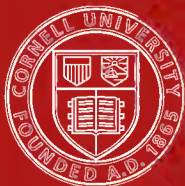


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RADIATION

“But, above all, we have heats in imitation of the sun’s and heavenly bodies’ heats that pass diverse inequalities . . . We make demonstrations of all lights and radiations and of all colours ; and of things uncoloured and transparent we can represent unto you all several colours, not in rainbows as it is in gems and prisms, but of themselves single. . . . We find, also, divers means yet unknown to you of procuring light originally from divers bodies. We represent also all manner of reflections, refractions and multiplication of visual beams of objects.”—*Bacon*.

RADIATION

AN ELEMENTARY TREATISE ON ELECTROMAGNETIC
RADIATION AND ON RÖNTGEN AND
CATHODE RAYS

BY H. H. FRANCIS HYNDMAN
B.Sc (Lond)

WITH A PREFACE BY
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D.Sc, F.R.S



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PREFACE

THE request made to me by Mr. Hyndman to write a brief introductory note, is one with which I have the greater pleasure in complying, because of the high appreciation I have formed of the spirit with which he has dealt with his subject.

In these days, amid the ever-increasing tendency on the part of writers of text-books of science to ignore those portions of the sciences that do not lend themselves to the curricula of set examinations, it inevitably follows that certain topics are neglected. The earnest student who cares more for advancement in knowledge than for a superficial examinational qualification finds many such *lacunæ*, particularly in the border regions between kindred sciences. But it is just these border regions which, neglected in the text-books, are the richest fields for research. In these, rather than in the oft-trodden highways of the fashionable text-book, or in the restricted area that fills the purview of the

professional examiner, is science progressing with the discovery of new phenomena, new generalizations, new relations. In the border-land works the pioneer.

The study of Radiation furnishes an example of such a border-land in science. Belonging both to the science of optics and to that of heat, it is incompletely handled if regarded merely as a branch of one or of the other. It reaches out into the sciences of electricity and of physiology. During recent years it has received a new impetus from the discoveries of Hertz, Langley, Röntgen, and others, opening out new and hitherto unsuspected fields of research.

A book which modestly presents a summary of knowledge in this domain is all the more welcome because of the reference it affords to the original sources. It helps to fill a void left by the artificial sub-division of Physics into separate class-subjects. To the real student of Physics who pursues the subject for its own sake it will be found most useful. It is much too good to be of use to one whose highest aim is to pass examinations.

SILVANUS P. THOMPSON.

AUTHOR'S PREFACE

THE subject of Radiation has been one of some considerable interest from very early times, not only because of its scientific importance, but because it is owing to radiation that there is any life upon this globe, and that man as a sentient being is able to appreciate the beauties of the world in which he lives.

The radiations of Sound, Light, and Heat each appeal to a separate sense, and hence can be appreciated to their proper extent when present together. This is not the case with the other radiations which are now known to exist, and which can only be appreciated by suitable contrivances. So much is this the case that, up to the last six or seven years, the radiations of Sound, Light, and Heat were the only ones which were known, with the exception of the very distinct phenomenon known as the negative

or cathode rays. During these last few years, however, the subject of radiation has received an enormous impulse owing to the discovery of remarkable and hitherto unsuspected radiations, first by Hertz and Lenard, and then by Röntgen and Becquerel. Not only has the whole scientific world been keenly interested in the attempts to elucidate these phenomena, but their very existence has suggested new experiments and comparisons among the radiations already known. During this period very important advances have been made in our knowledge of the infra-red and the ultra-violet radiations and of the electrical properties of the cathode rays, but they have only served to confirm, rather than to alter, the existing theories as to their nature.

In the following pages I have endeavoured to so correlate and arrange the results of the more important recent investigations, that a comparison of the principal properties of the different radiations might be facilitated; and also that where possible the general consensus of opinion with regard to the nature of any one of them might be ascertained. In this attempt I

have hoped to be serviceable to two classes of readers—to those who respectively have and have not some previous knowledge of the subject. The references to the original papers will, I trust, make it of some use to the former class, and perhaps to those who either are devoting or who intend to devote their time to research in radiation, by giving them something more than a mere bibliography. To these I must apologise for what may appear to be unnecessary explanations in certain portions. A previous knowledge of the subject is, however, possessed by comparatively few persons, and I have hoped to appeal to the much larger class who, though not conversant with the subject itself, still have a fair knowledge of general physical principles and methods of work. It would have been useless in the space at my disposal to try to state the subject to the person who was almost ignorant of physics, and I have hence throughout supposed some, and I hope not too much, knowledge of its elements. It has been my endeavour to reproduce as little as possible the parts of the subject given in the usual text books on the various branches, though

it has been necessary to include some parts in order to preserve the continuity of the subject.

I have not entered into the mathematical treatment of Radiation, because it can be found most completely discussed from two points of view in *Maxwell's Treatise on Electricity and Magnetism* and in *Rayleigh's Theory of Sound*, also less completely in a number of smaller works. Although portions of the subject of Radiation have been given in various works on Physics—such as those by Jamin and Bouty Vielle and Barker, while several volumes have been published dealing with the recently discovered radiations—still no connected account has been given, and it is this void that I have endeavoured to fill. The nucleus of the numerous references to be found in the text have been derived from the *Abstracts of the Physical Society of London* and from the *Electrician*, which publications have been of great service to me.

In the introduction I have avoided any attempt to define Radiation, or to rigidly distinguish it from such phenomena as convection or, conduction, whether of heat or of electricity,

in order not to complicate the subject. This course appeared to me to be justifiable, as my intention was rather to present the subject in a convenient form than to write an exact treatise.

I must claim the indulgence of my readers for the four new words that I have used. The terms, "transparent" and "opaque," when applied to the Röntgen rays, for instance, are liable to lead to some ambiguity, as they have had for some time a specific meaning with reference to light. By the use of words such as *Transradiable* or *Radiable* and *Nonradiable*, with their corresponding adjectives, this difficulty appears to be avoided. Again, the electromagnetic vibrations at present known fall naturally into two groups, which are at present unconnected by any links, but are completely divided by a space or *lacuna*. I have hence called all waves with a less frequency than this, *Infralacunal*, and all of a greater frequency, *Supralacunal*, and have thought the division convenient.

In conclusion, I have much pleasure in acknowledging considerable assistance from my friend Mr. C. H. Cribb, late Demonstrator at

St. Andrew's, in the collection and arrangement of the data. To my friend Mr. W. H. Austin, of Trinity College, Cambridge, I am under great obligations for his kindness in reading and criticising the proofs. He has helped me to remove obscurities, and has made many valuable suggestions. I am also greatly indebted to Prof. Silvanus P. Thompson for his kindly Preface, and to Prof. J. J. Thomson for the many ideas I have received from him.

H. H. F. H.

TRINITY COLLEGE,
CAMBRIDGE,
April, 1898.

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RADIATION

INTRODUCTION

A CONSIDERATION of the various conceivable ways in which a disturbance produced at one place can give rise to a disturbance at another, will show that they may be conveniently referred to four groups. We may consider that the distant disturbance is produced

(1) By means of some *mechanical* connection.

(2) By *action at a distance*.

(3) By the actual projection of *something* from the one place to the other.

(4) By the transmission of *energy* through a *medium* extending continuously between the two places.

The groups (1) and (2) are really converse

to one another, the one supposing a direct connection and the other no connection at all. The first could clearly not be used for the explanation of any radiation, but the second has had a very wide application in the past, though it is now only retained in Physics in connection with gravitational phenomena. The phrase is, however, essentially opposed to the whole conception of radiation, and its use can only be regarded as a convenient mode of confessing our ignorance of the nature of the connection between two dependent but apparently disconnected phenomena.

For the subject of radiation we are hence reduced to a consideration of the varieties of groups (3) and (4). The former was adopted in the Emission theory of radiant heat and light, which is now definitely abandoned; though emission theories are still in vogue for a few disconnected phenomena. Such a theory was proposed for both the Cathode and Röntgen rays at an early stage in their respective histories, and is retained for the former. The Röntgen rays have been also considered to be projected vortex rings (p. 266) which would

belong to this class. Lastly, the exciting cause of our sense of smell appears to partake partly of the nature of a radiation, though it is closely allied to diffusion.

The fourth possibility has long been the acknowledged mode of accounting for the propagation of sound, and is now universally adopted to explain not only the radiant phenomena of light, heat, and electricity, but also certain more recently discovered radiations.

The radiations to be discussed in this book, will be divided into those which occur in matter (Part I.), in the Ether (Part II.), and those recently discovered varieties which have not had their nature fully determined (Part III.). It is desirable, however, before dealing with any particular class of radiant phenomena, to briefly refer to the general nature of the disturbance or change of which the phenomena are the manifestations, and then to discuss the *medium*, and the properties it must have to enable it to fulfil the demands made upon it. The subject of vibration and wave motion can be treated from a broad general standpoint

quite apart from the medium in which it takes place, premising only that the latter *must have* certain essential properties before it will transmit wave motion at all.

Vibration and Wave Motion. The essential meaning of the word vibration, divesting it of the purely mechanical ideas generally attached to it, is that some property goes through a definite series of change at recurring intervals of time. For the present purpose, attention need only be paid to those vibrations in which these intervals are equal and which are hence said to be *isochronous*.

The simplest vibrating system is that of a vibrating point, and all other systems can be referred to this. A point starts from rest, and, moving through a certain series of positions, finally returns to its original one. The path described may have any form, but at present only those curves which *do not cut themselves* need be considered. With this limitation the two extreme cases are a circle and a straight line.

In Fig. 1, suppose a point P moving round

the circle $P C D$ in the direction of the arrow with uniform velocity V , which is equal to $\frac{2 \pi a}{T}$, where a is the radius $O D$, and T is the *Period* (the time of a complete revolution in seconds). From the point P imagine a perpendicular to be let fall with its foot M always

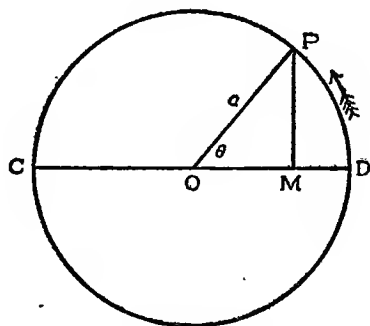


FIG. I.

on the diameter $C D$. As P moves round the circle, M is said to move backwards and forwards with a *Simple Harmonic Motion* (S.H.M.).

The motion on any closed curve of the nature considered above can be represented as the sum of a series of Simple Harmonic

Motions with special intensities and periods. The radius a is usually known as the *Amplitude*; it is the maximum value OM of the displacement of the point M from the centre, and its square is taken to be a measure of the intensity of the vibration.

The angle POD (θ), which the radius has swept out in the time t from the commencement of the vibration, is known as the *Phase*. The *Frequency* is the number of complete vibrations per second, and is obtained by dividing unity by T (the period), *i.e.* $N = \frac{1}{T}$.

The effect of giving a Simple Harmonic Motion to one end of a string, which may be looked upon as an infinite number of points in line, is to cause each point to take up the successive positions of the end at successive times; and as the end repeats its series of positions at equal intervals of time T , the phenomena will be periodic, and a number of points, such as C , D , etc. (Fig. 2), will be in the same position, and moving in the same direction (*i.e.*, in the same *phase*) at the same time. The wave length is then CD , and the amplitude of the

wave AB . The velocity V with which this wave will travel is clearly equal to the frequency (N) multiplied by the wave length (λ).

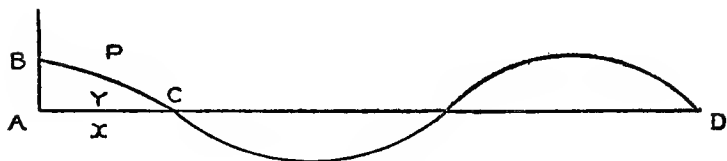


FIG. 2.

Representing the displacement of the point P (which is supposed to be moving with velocity v) by y , and its distance from the origin by x , Newton assumed that the equation $y = a \sin \left\{ \frac{2\pi}{\lambda}(vt - x) + A \right\}$ expressed their relation in time and space.

This equation is applicable to two different cases: (1) When x is supposed constant, it refers to a single particle, and the abscissa of the curve is vt ; (2) when t is constant, it refers to the simultaneous displacements of all the particles, and x is then the abscissa of the curve.

A vibration produced in a continuous and homogeneous medium will necessarily travel in

all directions, and the motion along any radius will be of the nature considered above.

With a symmetrical disturbance, if the medium is homogeneous and isotropic, the position of those points which are in the same phase at the same instant, that is to say, the wave surface, will be the surface of a sphere, and the entire undulation may be considered as an infinite number of such spherical surfaces.

A vibration may consist of displacements *in* the direction of propagation when it is said to be *longitudinal*; or at right angles to this, when it is known as a *transverse* vibration, or in any other direction which may be resolved into these.

It is very frequently necessary, however, to consider the conditions when two or more vibrations are separately acting at the same point at the same time; but as any change of the medium can really only occur in one sense at the same time at any point, it is clear that by a process of summation we can arrive at the correct conditions. The general discussion would be quite outside the present subject, and

we shall only consider briefly a few of the more marked and commonly occurring cases.

With collinear vibrations it is sufficient to add algebraically the displacements at the same instant for all points to obtain the compounded result, and if the periods of the compounds are commensurable their product will be the period of the resulting vibration. With two vibrations of amplitude a and a' , taking place at right angles, and having equal periods, the form of the vibration depends upon the difference of phase $(\theta' - \theta)$ between the components.

When $(\theta' - \theta) = \frac{1}{2} n T$, the resultant motion is *rectilinear* with an amplitude $= \sqrt{a^2 + a'^2}$.

When $(\theta' - \theta) = \frac{1}{4} (2n + 1) T$, the resultant motion is circular when $a = a'$, and elliptical when these are unequal, with the axes of the ellipse respectively parallel to the component vibrations.

When $(\theta' - \theta)$ has any intermediate value, the motion is also elliptical, but the axes of the ellipse are inclined to the directions of the vibrations. The quantity n in the above equations may signify any positive integer including zero.

When the directions of vibration are not at right angles, or collinear, the resulting form is always elliptical when the periods are equal; while the cases where they are unequal do not concern the present subject.

The most superficial observation of different media would give some idea of the properties

The Medium. a medium must possess in order to transmit vibrations such as we have just briefly considered; such materials as sand or cotton being obviously quite inadequate. For any medium to be able to transmit, even approximately, such vibrations, it must obey Hooke's law, "*ut tensio sic vis*," within the limits of the displacement produced, and for a displacement of the required character. This is equivalent to saying that the particular elasticity of the medium which is involved must not depend upon the *amount* of the displacement within the required limits.

In any homogeneous medium we know of three different but related modes in which forces can be applied, so as to produce corresponding stresses, for considering any particular unit, we can

1. Elongate or shorten it, *i.e.* change its length.
2. Enlarge or compress it, *i.e.* change its volume.
3. Twist it, *i.e.* change its shape.

It is clear that only media with a specific form can offer that resistance to this last change which constitutes the measure of the elasticity.

The only other constant of the medium which need be mentioned is the density. This is a ratio expressing the quantity of matter in unit volume of the substance; it varies in known substances between those of Hydrogen and Iridium, the latter having about 250 times the density of the former.

The Velocity. A vibration of the kind considered above, will travel with a velocity which is equal to the square root of the ratio between the particular elasticity called into play, and the density of the medium in which it is travelling, $V = \sqrt{E/d}$.

PART I

MATERIAL VIBRATIONS

As all our conceptions of vibratory movement are based upon the phenomenon as it occurs in matter, a brief study of the commonest form of material vibration, and that which has received most attention, may pave the way for the consideration of vibrations in a medium so intangible and so difficult of investigation as the Ether. Many substances approximately fulfil the conditions laid down in the last chapter as necessary for the propagation of vibratory movement, and they may therefore be taken as fairly trustworthy guides to what might be expected with a hypothetically perfect medium.

In materials composed of a multitude of separate units, as all the forms of matter are assumed to be, there may obviously occur

vibrations affecting the individual units severally, and vibrations, or rather undulations, which affect the material as a whole. It is quite clear that only the latter class can be of the nature of radiation. The former constituting the phenomenon of heat do not therefore concern us here, except in so far as they are the movements into which all other forms of motion, including those connected with sound, eventually degrade.

Little is known as to the ultimate nature of these heat vibrations, or their relation to the movements of translation assumed by the kinetic theory of gases. As to the mechanism of the larger vibrations of sound which assume the medium homogeneous, more is known than of that of any other kind of molecular movement.

(A) LONGITUDINAL VIBRATIONS (SOUND)

These vibrations, taking place in the direction of propagation, consist of successive condensations and rarefactions; that is to say the individual particles (molecules) of which the medium is composed, become at any one spot more closely aggregated or more widely separated from one another in regular sequence. It is obvious from this that the state of aggregation and the mode of arrangement of the molecules, viz., the nature of the medium, must profoundly influence the rate of propagation and other properties of the vibration. However, in the absence of any exact knowledge as to the true explanation of the differences between different kinds of matter, it is simpler, and for the present purpose sufficiently correct, to regard all material media as continuous elastic substances, each with its own coefficient of elasticity.

Under the heading Sound must be included all the longitudinal vibrations which take place in matter. As the term "light" is often used for undulatory movements of the ether which are invisible, so with sound, there are analogous movements which are altogether inaudible.

In the former case, it is true, special words are used to distinguish the radiations that affect our eyes from those that do not, but sufficient justification for this is found in the somewhat widely differing properties of the latter.

In the case of sound, no such differences are at present known, and the range of the inaudible is probably not great compared with that of the audible phenomena. What the former range is remains at present undecided.

The velocity of propagation of sound as of other radiations depends upon the relation between the elasticity and density of the medium in which it is travelling. The amplitude of the vibration has also some effect on the velocity, inasmuch as very loud sounds have been found to travel faster than those of less intensity (Rayleigh).

Solids differ from fluids in having different

coefficients or moduli of elasticity, depending on the manner in which the stress is applied.

In general solids have simple rigidity, volume—elasticity, and linear extensibility (Young's *Modulus*) of these the last is the one which is presumably concerned, although this is by no means certain. It is assumed to have been determined under adiabatic conditions, a condition *never* realized in practice. In solids, however, the difference between isothermal and adiabatic changes is very small, and can be calculated from thermodynamical considerations. In fluids the only possible elasticity is that of resistance to compression, which in liquids is known as volume elasticity (K), and in gases as adiabatic elasticity (γp).

K is here supposed to have been determined under adiabatic conditions, or to be corrected for change of temperature, γp is already corrected, the quantity γ being the ratio of the specific heat of the gas at constant pressure, to that at constant volume. Newton used the uncorrected formula $V = \sqrt{p/d}$ and got uniformly low results, Laplace first correcting the

formula by the introduction of γ . The velocity of sound in air (or other gas) is very nearly the same whether the gas is free or enclosed. In air, at 0° C. and 760 mm. pressure, it is equal to 1092 feet, or 35.82 metres per second.

The intensity on the other hand in free air varies inversely as the square of the distance from the source, while in tubes although the energy of the vibration is more rapidly converted into heat than in the open the intensity diminishes very slowly.

Influence of Pressure.—Since both the adiabatic elasticity and the density of gases are proportional to the pressure, the latter does not affect the velocity of sound in gases.

Influence of Temperature.—The ratio of the velocities of sound in the same gas at different temperatures, is equal to the square root of the ratio of the absolute temperatures

$$\frac{V_1}{V_2} = \sqrt{\frac{273+t_1}{273+t_2}}$$

Sounds are distinguished from one another by the three fundamental properties of all undulations: i. Frequency; ii. Amplitude; iii. Character, or wave form; which correspond

to the sensations of *pitch*, *intensity* or loudness, and *timbre*.

The correspondence between pitch and frequency is complete, but loudness bears no direct relation to amplitude, though with two sets of waves of the same form and frequency, that of the greater amplitude will sound the louder.

Timbre seems to be due to the presence and relative intensities of the higher harmonics of the primary sound, and in the case of some instruments, of noises unavoidably produced at the same time. It is generally characteristic of the particular source employed for the production of the sound.

In the case of light no corresponding quality is recognized, but as the whole visible spectrum is comprised within a single octave, the presence of higher harmonics would only be detected by photography, if at all.

§ I.—Production and Frequency (Pitch).

Sounds can be produced *directly* by causing the air to vibrate, or *indirectly* by throwing

some substance into a state of vibration, which in its turn affects the air.

The latter is by far the most common, and is the cause of almost all natural sounds ; but organ pipes and some other wind instruments are so formed that when a stream of air is sent through them, it is thrown into vibration.

According to Preyer, the lowest notes that are appreciable to the human ear have frequencies of between 16 and 24 vibrations per second, and the highest as many as 41,000. Individuals differ considerably in their power of appreciating high notes, while some animals seem to be very highly endowed in this respect.

In consequence of the comparative slowness of the vibrations concerned, it is possible to produce sounds of a perfectly definite pitch at will. Amongst the many convenient instruments for the purpose is the Siren, which allows of any required number of puffs of air (within the limits of the apparatus) being produced in a second.

The note emitted by a vibrating string depends upon its length (l), and the velocity (V) of the pulse in it. The latter will depend upon

the nature of the vibration. When this is longitudinal $V = M/d$, where M is the value of Young's Modulus for the string; but when transverse $V = F/m$, where the stretching force F is the measure of the elasticity, and m is the mass of unit length of the string. Since also $V = N\lambda$, the frequency is known if the ratio between λ and l is given. In the simplest case, when the note is the fundamental, $\lambda = 2l$.

The note emitted by a vibrating column of a gas depends upon the velocity of sound in the gas, and on the length of the column; the position of the loops being determined by the fact that the open end of the tube and other openings, if any, must each be at the middle point of a loop.

§ 2.—Appreciation of Sound.

The ear has a considerably wider capacity of appreciation with regard to sounds than the eye has to light, inasmuch as its range extends over from 6–10 octaves, while the eye can only deal with one.

In sensitiveness to minute changes of fre-

quency the ear also has the advantage, for according to v. Helmholtz (*Sensations of Tone*, p. 221), a trained musician can distinguish musical sounds differing by only $\frac{1}{64}$ of a semi-tone, which is equal to '0013 octave, and this in the case of light would be equivalent to distinguishing between vibrations differing in wave length by about 5.2×10^{-10} metres, a difference equal to that between the two *D* lines (Watts' *Index of Spectra*, 1889) which certainly could not be estimated as one of *colour*.

The duration of the impression is in the case of the ear less than in the case of the eye, for according to the same authority, the ear can distinguish as separate sounds 132 impulses per second, while any number of visual impressions over 24 per second¹ are fused together and appear continuous. Of course the eye has special functions of its own in regard to which no comparison with the ear is possible. The faintest audible sound had in an experiment of Lord Rayleigh's (*Proc. R. S.*, 1897) an amplitude of 8.1×10^{-8} cms. when its frequency was 2730.

¹ The number varies considerably with the intensity.

§ 3.—Reflection and Refraction.

The reflection of sound obeys the same laws as that of light as far as has been ascertained, and the phase of the vibration is inverted on reflection from a medium of *less* density than the one in which it is travelling. When the medium is solid the condition of the surface has no effect if the irregularities are small.

Refraction takes place under the same laws that apply to light and heat, when sound waves pass from one medium to another of greater or less density, but the difference in the density must only be slight, for otherwise most of the energy is reflected at the first surface of the new medium. Practically, therefore, refraction is limited to cases where the sound passes from one *gas* to another, and for experimental purposes it is even necessary to choose gases whose molecular weights do not differ very widely. A sound passing from air, for instance, into hydrogen, is largely reflected at the surface of the latter.

Prisms and lenses may be made containing carbon dioxide gas, and the sound wave will be

caused to deviate by the former, or converge by the latter, if the waves are short compared with the dimensions of the prisms or lenses.

Since, with the exception already noted on p. 16, all sound waves travel with the same velocity, nothing like a refraction spectrum can be obtained. A kind of spectrum has, however, been obtained by means of a large diffraction grating (*Phil. Mag.*, 1894, p. 81).

§ 4.—The Absorption and Transmission of Sound.

Since sound is a movement of matter, the most effectual barrier to its progress is a vacuum, and, although all homogeneous substances transmit sound, it is very easily stopped by the multitude of internal reflections which occur in a mass of powder or other loose material.

Some substances are able to transmit sounds of one pitch more readily than those of another, and presumably if two such sounds were produced together in the neighbourhood of such a substance, a kind of selective absorption would occur. It is a well known fact that

shrill sounds, though most effective at short distances for attracting attention, have not the same penetrative power at long ranges as notes of a much lower pitch, hence the low note of the fog horn.

§ 5.—The Interference of Sound.

This phenomenon can be produced either with a direct and return wave, as with electrical waves (p. 112), or from two sources of sound which are vibrating in the same manner, by making their paths differ by half a wave length (Mayer). The first method is that employed for a determination of the wave length. The position of the nodes can be determined in several ways; for audible waves, with a wave length of more than a few centimeters, lycopodium dust is convenient, as it congregates at the nodes; and for waves of higher frequency a sensitive flame is used.

When two interfering sounds, of equal amplitude, are of slightly different frequencies, they will intensify and neutralize one another's effect at definite and recurring intervals of

time, the result being that the sound is periodically loud and soft.

The frequency of this period is easily derived from those of the respective waves, since if a and $a + b$ are the frequencies, b is the number of times that the two vibrations coincide completely, *i.e.* the number of maxima per second.

The maxima, or beats, are of the greatest value in tuning two notes to unison, for as the latter approach more and more nearly to this condition, the beats decrease in frequency, until at unison they cease altogether. The operation is obviously easiest when the sounds are prolonged enough to enable the beats to be easily counted.

(B) TRANSVERSE VIBRATION IN MATTER.

It has been mentioned on page 11 that these can only occur in solids, and even in them but few cases are known. Some types of earthquake seem to partake of this nature, and it is possible that the earth tremors which are constantly taking place in certain districts may be so also. As a rule, the coefficient of rigidity is of a lower order than the coefficient of volume elasticity, and measurements of the rate of propagation of earth waves show that two series of vibrations may exist at the same time, the direct or longitudinal and the transverse. Mallet¹ observed a velocity of 800 feet per second in some experiments at Naples, but much lower values have been obtained by other observers, notably by Milne and Grey (*Proc. R. S.*, Dec., 1891) for artificial earth waves. They found a velocity of 438 feet per second for the direct, and 357 feet per second

¹ The Great Neapolitan Earthquake of 1857. R. Mallet.

for the transverse vibrations, the medium being a hardened mud. Although the direct waves had a greater amplitude (.5 m. at 50 feet) and frequency, they were much more easily damped by the mud or other media than the transverse waves.

PART II

THE ETHER AND ETHERIAL VIBRATIONS

OF the need for a medium to account for the propagation of light and other forms of radiant energy it is hardly necessary to say anything here. The absolute rejection of the emission theory of light leaves a choice only between an Ether theory and action at a distance ; and the latter being contrary to universal experience can only be regarded as another way of saying we do not know.

The necessity for an all-pervading medium may the more readily be taken for granted inasmuch as the general notion has been in men's mind for centuries, and its nature and properties were discussed by metaphysicians and astronomers long before they came within the reach of experimental method. Hypothetical media were invented to explain all sorts

of phenomena until, to use the words of Clerk-Maxwell, "all space had been filled three or four times over with ethers."

Many of the reasons advanced to show the necessity for some of these media were not such as would commend themselves to the modern scientific mind, but, as knowledge increased, phenomena were brought more into line and the number for which such a mode of explanation was judged necessary became less. At the same time the one Ether that was destined to survive—that originally suggested by Huygens to explain the propagation of light—had its functions added to and a greater burden of explanation put upon it, thus enormously increasing the difficulty of making the theory fit the facts.

At the present time the actual existence of the Ether is regarded by many as a demonstrable fact (see below), and the generalisation connected with it, though exceedingly intricate in detail, is at the same time one of the simplest and most far-reaching in all scientific history.

Although it will be briefly alluded to it

is not proposed to deal here with the Ether theory in its widest range as affording an explanation of the ultimate nature and properties of matter, but only to treat of it as the medium for the radiant phenomena of light, heat, and electricity.

Looked at from a purely elementary standpoint, to be able to fulfil its functions properly, the Ether must be conceived as filling all space, and not only surrounding all matter, but penetrating between its ultimate particles. It must offer no measurable resistance to the passage of matter through it, and must be able to transmit energy without loss from one part of it to another. This energy being conveyed in the form of undulations will obviously not be transmitted instantaneously.

To be able to transmit vibrations at all, the Ether must possess some property analogous to a finite density, *i.e.* it must have inertia; to be able to transmit transverse vibrations, it must possess rigidity, *i.e.* must offer resistance to alteration in *form*. Fluids, as has already been mentioned, possess only volume elasticity, and can therefore transmit

longitudinal vibrations only. In view of the enormous rapidity with which light and the other electro-magnetic vibrations travel, and of the fact already stated (p. 11) that the rate of propagation of a vibration is equal to $\sqrt{E/d}$. (E in the case of Ether being the elasticity of figure just referred to, and d the equivalent of density), it is obvious that the rigidity must be enormous in proportion to the density. Methods by which these factors have been determined, will be referred to later on.

As regards its actual nature or structure opinions still vary. It must be conceived as being uniform throughout space, but in the neighbourhood of matter it has an apparently increased density (*see* p. 39). Whether it is to be considered continuous in structure is yet unsettled. The velocity with which light and electro-magnetic radiations travel in it would seem to indicate that the structure could not be molecular like that of a gas, for instance, as the energy of the vibration would be very rapidly converted into heat. According to Clerk-Maxwell,¹ in a gas a transverse vibra-

¹ *Encyclopædia Britannica*, article "Ether."

tion would have its amplitude reduced to $\frac{1}{500}$ of the initial amount before it had travelled a distance equal to one wave length, moreover the velocity of transverse vibrations in solid transparent substances is hundreds of thousands of times less than that of light in the same substances. The existence of rigidity also demands a continuous and not a molecular structure inasmuch as it is difficult to see how a set of widely disconnected particles could have this property at all.

On the other hand, Karl Pearson¹ finds it "difficult to realise how a continuous and same medium could offer any resistance to the sliding motion of its parts," and also to see how it could allow of any motion other than one of rotation.

The elastic solid theory conceives of it as a continuous jelly-like substance, almost absolutely incompressible, with a rigidity like that of a solid, so that at one and the same time it must offer resistance to change of shape, and offer no resistance to the passage of bodies through it, it must possess a considerable

¹ *Grammar of Science.*

rigidity while having an extremely low density. Such a medium is unlike anything we know. Neither the most perfect fluid nor the most perfect jelly will satisfy the requirements of the Ether theory.

S. Tolver Preston¹ advocated a corpuscular ether theory: according to which the Ether is something like a gas, the molecules of which have a mean free path greater than any interplanetary distances, and so never colliding with one another. He thought that to regard the Ether as continuous was a retrograde movement which complicated our notions by introducing fresh ideas contradictory to all our experience, and that if the Ether is to affect our senses it must differ only in degree and not in kind from ordinary gross matter.

The Jelly theory of Sir George Stokes² represented the Ether as a perfect jelly for sliding strains of small magnitude and as a perfect fluid for larger strains.

Lord Kelvin³ has advanced a theory, in the

¹ *Phil. Mag.*, 1877.

² *Mathematical and Physical Papers*, i. 125-9; ii. 12-13.

³ *Proc. Roy. Soc.*, June, 1896.

first instance to explain the action of magnetism on light, which virtually gives the Ether a molecular structure without strictly speaking interfering with its homogeneity. According to it, parts of the medium are in a state of rapid and perpetual rotation. This rotation conferring on it a rigidity just as a rubber tube becomes stiff when a rapid current of water is sent through it.

As regards the nature of the vibrations that occur in the Ether, the electro-magnetic theory of Clerk-Maxwell¹ avoids many difficulties by regarding them, not as being *movements* of part of the medium, but as consisting of a separation or decomposition of the medium into two constituents. Such decomposition is resisted in free Ether, the forces tending to effect it taking the place, in this theory, of the ordinary mechanical shearing forces. The resistance to them constitutes the rigidity of the Ether by which it is enabled to propagate transverse vibrations. In the presence of matter, on the other hand, the Ether offers a much less resistance to this decomposition, the actual amount

¹ *Encyclopædia Britannica.*

being inversely proportional to the electric conductivity of the substance. If very great the body would be a bad conductor, if very little a good conductor. Whether the Ether itself is a conductor of electricity or not is yet unsettled, its obvious transparency seems, however, to tell strongly against its being so.

In turning now from the theoretical consideration of the matter to the actual properties it has been found possible experimentally to investigate, as has been stated above, its objective existence is now by many assumed. Thus Lord Kelvin writes¹: "Of one thing we are sure—the reality and substantiality of the Ether." On the other hand, Karl Pearson² considers that Hertz's experiments had not "logically demonstrated the perceptual existence of the Ether" however much they might have done towards experimentally increasing the validity of the idea. At the same time he admitted that many of its properties were not likely to come directly within the range of our sense organs.

¹ *Constitution of Matter.*

² *Grammar of Science*, p. 214.

Lord Kelvin has attempted to weigh¹ the Ether, but no evidence has yet been brought forward to show that it is gravitationally attracted by matter, or that the two mutually attract one another; and there is no evidence indicating any tendency on the part of the Ether to accumulate in the neighbourhood, for instance, of the earth or the sun. If, however, the Ether is to be the chief factor in the explanation of gravitation, as is suggested on p. 41, it would seem to be rather an inversion of facts to talk about its having weight itself.

At the same time its density was calculated by Lord Kelvin,² in 1865, from the mechanical energy of sunlight at the earth's surface on the assumption that the amplitude of the waves was not more than $\frac{1}{100}$ of their length, the result being 9.36×10^{-19} .

De Volson Wood³ has calculated that a medium, to carry a pulsation from the sun to the earth with the velocity of light, and transmit 2.8 calories per minute, must have a

¹ *Lectures on Molecular Dynamics*, p. 206.

² *Trans. Roy. Soc. Edinburgh*, xxi., 61.

³ *Proc. Amer. Assoc. Science*, 1892.

density of 2.6×10^{-24} , so that a mass the size of the earth would weigh about 1.7 lb.

Compared with that of the air in space, the density of the Ether is enormous, for at a distance of only 4000 miles from the earth's surface the former has been calculated to be 10^{-126} .

Having thus got a value for the density, the rigidity can easily be calculated, and is found to be $\frac{1}{11}$, which, compared with that of steel, 842×10^{11} is altogether insignificant. However the elasticity of volume, as indicated by Faraday's well-known ice-pail experiment and others, is so great as to be practically infinite.

The above calculation has been made from the formula $V = \sqrt{E/d}$ where $V = 3 \times 10^{10}$ m. per second, this being the observed velocity of light.

Other transverse electro-magnetic disturbances are found to travel (within the limits of error of experiment) at the same velocity as light, which would be expected if both phenomena are the same, as Maxwell's theory assumes.

A most interesting point, in connection with which much experimental work has been done

and which is still far from settled, arises in connection with the behaviour of the Ether towards matter.

While, on the one hand, no evidences of the Ether attracting or being attracted by matter has yet been obtained, it is equally certain, on the other, that matter must be connected in some way with the Ether in order to account, for instance, for the diminished velocity of light in passing through transparent substances, as compared with its velocity in air or interplanetary space. Thus, in crown glass, light travels at the rate of 200,000 kilometres per second; while in air the velocity is about $\frac{1}{8}$ more.

It is not yet known whether the earth, in its motion, carries with it the Ether in which it is immersed, or whether the latter passes freely through it. Attempts to estimate the relative velocity of light with and against the motion of the earth in its orbit cannot be expected to show a sufficient difference in the results to prove anything, as the mere addition of the earth's velocity to that of the propagation of light would be almost inappreciable.

The experiments of Fizeau and Fresnel, also of Michelson and Morley, showed that light travelled more quickly in the direction of a rapid stream of water than against it; but the increase of velocity in the former case was less than would have been expected from the velocity of the stream. The velocity in the moving stream being found equal to that in the quiescent liquid $\pm \frac{7}{16}$ the velocity of the current. The meaning of the retardation of light during its passage through transparent matter is by no means clear. It may be due to an increased density, as suggested by Fresnel, or to a decreased rigidity or elasticity. If the former, it is difficult to see how the Ether, which is supposed to be incomprehensible, could become denser, and equally difficult to imagine any process by which matter could produce this effect.

It has been suggested that the increase in density is only apparent, not real, and that matter, in some way, "strains the Ether towards itself, thus slackening its tension inside bodies,"¹ without producing any real increase of density.

¹ Lodge, *Modern Views of Electricity*, p. 410.

This would afford a sort of explanation of gravity, as two bodies, both acting on the Ether in this way, would naturally tend to attract one another.

In addition to affording an explanation of the mode of conveyance of light, heat, and electrical radiations, it is now customary to also cast upon the Ether the duty of accounting for gravitation and of throwing some light, however dim, upon the ultimate nature of matter itself.

The molecular Ether of Le Sage, further worked out by John Preston, fulfilled the former function, but differed only in degree, and not in kind, from gross matter. Lord Kelvin's¹ suggestion is that the ultimate particles of which atoms are composed, *prime-atoms*, consist of Ether in a state of perpetual spin—vortex rings in fact.

Karl Pearson² calls in the aid of fourth dimensional space, and suggests that atoms are points in *our* space at which Ether flows in, and involving, of course, the idea of Ether *sinks*

¹ *Constitution of Matter*.

² "Ether Squirts," *Amer. J. of Math.*, xiii., 309-362.

or points at which the Ether flows out in corresponding quantity, as without these our Ether would not appear to us to be incompressible.

W. K. Clifford similarly makes use of the fourth dimension by imagining matter to be a sort of wrinkle in space, obviously conditioning a fourth dimension for it to lead into.

(A) LONGITUDINAL VIBRATIONS.

The view according to which light is propagated by elastic pulsations in a jelly-like medium requires in theory a compression and rarefaction wave normal to the (light) wave front. No such *optical* phenomenon has as yet been fully recognised, but it has been supposed that such longitudinal vibrations may be capable of existence.

The elasticity of volume concerned in such longitudinal vibration is as already mentioned (p. 38) almost infinite, the Ether being almost absolutely incompressible ; consequently the value for its elasticity divided by the very low density would make the rate of propagation such as would appear to us, with our present means of measuring time, absolutely instantaneous. However, true wave-motion appears to be quite inconsistent with really instantaneous propagation.

Lord Kelvin¹ has recently suggested a method for the artificial production of longitudinal vibrations. An insulated circular metal plate is surrounded by a metal case which is perforated, opposite the centre of the plate, by a hole through which a discharger passes; this can move backwards and forwards, and is connected to an influence machine or induction coil so as to give rapid changes of polarity. If then the plate be charged positively and the discharger pushed in until a spark passes between them, the result, as regards the space between the plate and the roof of the metal case, will be "either an instantaneous transmission of commencement or diminution of electrostatic force, or a set of electrical waves of almost purely longitudinal displacement according as Ether is incompressible or compressible."

The equations which Maxwell advanced as the basis of his theory do not admit of the existence of any longitudinal component, but Jaumann (*Elec.*, 36, p. 688,) has pointed out that a small deviation will make such longitudinal vibrations possible. The experiments

¹ *Proc. Roy. Soc.*, Feb. 13, 1896.

of Elster and Geitel (*Elec.*, 35, p. 272, 1895,) appear to show that such vibrations do exist at the *borders* of every ray of light, and hence presumably at the borders of every other electro-magnetic disturbance. The longitudinal waves are displaced by a quarter of a wave length with respect to the transverse, and from Elster and Geitel's measurements (*Wied Ann.*, 55, p. 695) it seems that the amplitude of the longitudinal component only reaches high values in media of low density, while its magnitude *increases* with the angle of incidence (p. 134).

(B) TRANSVERSE VIBRATIONS.

Adopting the electro-magnetic theory of Clerk-Maxwell the main properties of the Ether concerned in these vibrations will be the electrical rigidity already referred to and the density. The reciprocal of the former is usually expressed by the dielectric constant K , although the relation is probably not one of equality. As the absolute dielectric constant has not been ascertained, it is usual to consider that of the air as unity, although Lord Kelvin has given reasons for supposing it to be about 140. The *bound* Ether, *i.e.* that which is in the presence of matter, has, as already mentioned (p. 39), its density *apparently* increased, the effect being most marked in magnetic substances and reaching its highest value in iron. It is proportional to the magnetic permeability, μ , of the substance, of which the absolute value is also

unknown, air being again taken as unity. Lord Kelvin has here also given a value 8×10^{-24} derived from the above estimate of the density.

According to Maxwell's theory there are two manifestations of electrical energy at right angles to one another and to the direction of propagation of the vibration.

"One, the *electro-static*, depends on a property of the medium in virtue of which an electric displacement elicits an electro-motive force in an opposite direction, and per unit displacement inversely as the square of the dielectric co-efficient of the medium."

The other, the *electro-kinetic*, is the energy of the motion set up in the medium by electric currents and magnets, and exists wherever the magnetic force can be found.

§ 1.—Dimensions and Frequencies.

The phenomena of radiant electricity light and heat have been shown to be merely varieties of the same form of energy, and it is usual now to consider the vibrations which

affect us as light as being minute electrical waves, rather than the electrical vibrations as long light waves, although this latter view has been recently brought forward (Jaumann).

The transverse radiations known to us have an enormous range in size, the longest electrical waves hitherto measured being 10^{16} or *ten thousand billion* times as long as the extreme ultra-violet, and should, as seems probable, the radiations discovered by Röntgen, Le Bon, and Becquerel prove to be still shorter waves of the same nature, the range will be even further increased. It is also possible that there may be waves of magnetic action reaching the earth from the sun still longer than those here mentioned.

The following table shows the wave length and the frequency for every type of ethereal vibration known to us as far as these have been actually measured or deduced on theoretical grounds.

The table may be considered as representing specimens from different parts, so to speak, of the whole gamut of known ethereal vibrations.

Starting with the enormous waves which are

TRANSVERSE VIBRATIONS

Source.	Wave length (λ) in terms of 10-10 metre.	Frequency, i.e. number of vibrations per second. (N)	Authority.
Magnetic waves from the sun	20,000,000,000,000,000,000 (about 1'24 million miles)	154 (one oscillation in 6½ seconds)	Lodge ¹
Flash of lightning . .	178,300,000,000,000,000 (about 11,000 miles)	167	Lodge
1 microfarad, discharging through 1 sec. ohm.	19,000,000,000,000,000 (about 1,178 miles)	157	Lodge
An open induction coil	300,000,000,000,000 (about 18.6 miles)	16,000	Lodge
A pint Leyden jar . .	170,000,000,000 (about 19 yards)	18,000,000	
Oscillator	28,000,000,000	100,000,000	Hertz ²
Thimble-sized jar . .	7,500,000,000	400,000,000	Lodge
Oscillator	6,600,000,000 (about 26 inches)	450,000,000	Hertz
Oscillator	40,000,000 (about 16 inches)	50,000,000,000	Lampa ³
Continuous reflection .	244,000	12,300,000,000,000	{ Rubens Nichols ⁴
Maximum intensity between 0 and 100	55,000	54,500,000,000,000	Langley
Infra-red limit of solar spectrum	27,000	110,000,000,000,000	Langley
End of <i>visible</i> spectrum	7,740	387,500,000,000,000	Watts ⁵
A line	7,594	394,500,000,000,000	
D line	5,896	509,000,000,000,000	
H ₃ line (Calcium), limit of violet	3,933	762,800,000,000,000	
Aluminium line 328 ex- treme ultra-violet .	1,852	1,619,000,000,000,000	Kayser & Runge ⁶

¹ *Modern Views of Electricity.*
² *Electrical Waves.*
³ *Wind Ann.*, 61, 1, p. 79.
⁴ *Phys. Rev.*, 22.
⁵ *Index of Spectra.*
⁶ *Abhandl. d. Berl. Akad.*, 1891.

supposed to proceed from the sun, we may consider that there exists an unbroken series down to waves about 4 mm. long, which are the smallest that can as yet be produced in the laboratory. Many specimens of this series can be produced at will, and the study of their properties shows that in nearly all their essential characteristics they are the same.

Between the electrical waves of 4 mm. in length and the longest heat wave which has been measured a gap exists which, though comparatively small, is of considerable importance, for the radiations on either side of it differ widely in many of their properties, although their general characters are the same. For distinguishing these two sets of vibrations from one another the terms *infra-* and *supra-lacunal* may be conveniently employed. What the wave length of the radiations emitted by bodies at temperatures approaching the absolute zero would be it is difficult to conjecture, but it is perhaps not impossible that the magnetic properties which many bodies exhibit at low temperatures may be connected with the emission of small electrical waves.

The frequency of the waves at one end of the visible spectrum is about twice that of those at the other, so that the light waves may be considered as an octave. The whole series then consists of about three hundred billion octaves, and if a line whose length is the distance from the earth to the sun (about 92·8 million miles) is used to represent a scale of wave lengths, the gap would be $\frac{1}{8}$ mm. long and the visible spectrum would only cover $\frac{1}{80}$ mm. or $\frac{8}{10000}$ of an inch.

§ 2.—Production.

In dealing with the production of ethereal vibrations it need hardly be pointed out that the phrase is, strictly speaking, only applicable to those vibrations which are the result of laboratory experiments, and even in their case means little more than a knowledge of the requisite conditions for starting the particular kind of radiation required. Of the ultimate mechanism by which the effect is produced practically nothing is known.

In the present state of our knowledge it would have been possible to make a sharp

division between those radiations which can be artificially produced, and those which occur naturally. In view, however, of the short time which has elapsed since the Ether was first recognised as the medium for electrical phenomena, and of the difficulty of detecting waves of an electrical nature, owing to their not directly affecting any of our sense organs, it must be regarded as well within the bounds of possibility that waves of every possible frequency may occur naturally under certain conditions, but because they have never been looked for, or because of the difficulty of such a search, they have hitherto escaped detection.

The mode of production (limiting the meaning of the phrase as suggested above) assumes its greatest importance in connection with the electrical or infra-lacunal radiations, inasmuch as those we can deal with are almost entirely of laboratory origin. It will therefore be convenient to treat them separately from the others.

The waves have such a vast range in size that it will be necessary to take one particular set as a type for special consideration, after the general principles of their production have been discussed.

**Infra-lacunal
Waves.**

Consider two metallic spheres which are at a distance depending upon the dielectric and the potential which is to be employed, and suppose that they are being gradually charged from some source to equal and opposite potentials. The seat of the charges is in the surrounding Ether which is put into a state of strain proportional to the potential. If this is continuously increased the breaking strain is ultimately reached and the result is a spark between the spheres.

In general, if this spark is examined in a rapidly revolving mirror it will be found to consist of a large number of minute sparks coming alternately from the two electrodes.

The effect is as though too much electricity went over in the first spark and too much came back in the second, so that the discharge has the character of an oscillation.

Any arrangement by which electricity can be accumulated, as in the two spheres mentioned above, is called a condenser, and the amount of electricity (Q) it requires to charge it to unit potential (V) is known as its capacity (C) hence $Q=VC$. The theoretical investiga-

tion of the mode of discharge of a condenser was first made by Lord Kelvin in 1853, but the details would be beyond the scope of this work so that the result only must suffice.

In any condenser circuit—

If the capacity of the condenser $= C$

Co-efficient of self induction of the circuit $= L$

Resistance of the circuit $= R$

The periodic time of the vibration $= T$

then

$$T = \sqrt{\frac{2\pi}{\frac{1}{C.L} - \frac{R^2}{4L^2}}} = 2\pi \sqrt{\frac{4CL}{4L - CR^2}}$$

which, when the resistance of the circuit is small compared with the reciprocal of the capacity, reduces to

$$T = 2\pi \sqrt{C.L}$$

In the general equation we see that by suitably arranging the ratio of $4L$ to CR^2 the discharge may have any character.

For if $4L < CR^2$ the spark is continuous and there is no oscillation ;

$4L = CR^2$ the time of discharge is the shortest possible, but there is still no oscillation ;

$4L > CR^2$ the discharge is oscillatory :

a parallel case is observed with the elastic recovery of solid bodies.

The inertia of the vibration is supplied by the quantity L , the coefficient of self induction ; this depends directly upon the form of the circuit and can be calculated from it.

It is clear that here we have a method for producing vibrations of this character of any wave length and frequency at will, and were it not for experimental difficulties this could certainly be done.

The wave length of the vibration produced by the electric oscillations of a charged sphere is found to be equal to about 1.4 of its diameter (J. J. Thomson), and it is on this assumption that the first values in the table on page 49 are calculated.

The waves which were the subject of the brilliant investigations of Hertz may be taken as a special example since they have been the most thoroughly studied, and all subsequent work has been on the same principle. The vibrator he used consisted essentially of two metal balls which were attached to rods or plates to increase their capacity if required.

The direction of the electric force was found to be parallel to that of the vibrator (vertical in the experiments), and the lines of magnetic force were circles round it. Hence the electric and magnetic forces are in the wave front, and at right angles to it and to one another.

The energy of the radiation can be calculated from a consideration of the dimensions, for if the two spheres were of 15 cm. radius and placed at a distance of 1 cm., then the difference of potential necessary to produce a spark would be 120 cgs. units or ± 60 for any one sphere. This quantity is the result of experiment and cannot well be deduced.

$$\begin{aligned}\text{The whole energy} &= (\tfrac{1}{2} QV - Q'V') = CV^2 \\ &= 15 \times 60^2 \text{ ergs.} \\ &= 54000 \text{ ergs.,}\end{aligned}$$

which is about that of one gramme after falling through 55 cm.

Subsequent experimenters have modified the form of this apparatus with a view of getting a vibration of a much greater frequency than Hertz could obtain.

To effect this it is clearly essential that the capacity of the radiator should be largely

reduced; this has been mainly done by the obvious method of decreasing the size of the discharging balls. Some have used a row of small balls imbedded in paraffin, others two small balls on opposite sides of a rather larger one,¹ all being made of platinum to avoid the corroding action of the spark as much as possible and being mounted so that their distances could be accurately adjusted.

With these methods of production it has been found that two series of waves are produced, one of which depends upon the dimensions of the oscillator, and the other on those of the receiver (see § 3), and the series which has the greater effect is the one investigated.

Some supra-lacunal waves are emitted by every substance, under all possible conditions except perhaps at the absolute zero of temperature, could this be obtained; though other rays may be emitted at the same time.

The character and intensity of the radiations seem to depend on three variables, the temper-

¹ Lodge, *The Work of Hertz and some of his Successors*, 1894. See also Bose, *Proc. R. Soc.*, vols. lix. and lx.

ature, the nature of the substance, and the condition of its surface.

The first is found to affect the radiation in two ways, for, as shown by Tyndall, The Temperature. increasing the temperature not only increases the frequency but also the amplitude of the vibration. This is shown when such a substance as lime (which is practically unaffected by great heat) is gradually raised from the lowest to the highest attainable temperature. (*Heat a Mode of Motion.*)

Below -110° C. the rays emitted are found to have different properties¹ to those above this temperature, see p. 85.

From about -70° to a red heat (about 550° C.) the waves have all the same character; but as the temperature is raised, new waves of a continually increasing frequency are emitted, and the existing waves are augmented in amplitude.

Between a dull red and a white heat light waves are produced, the advent of the shorter waves at this stage causing the change of colour; finally, with a further increase of temper-

¹ R. Pictet, *C. R.*, p. 1202, 1894.

ature, invisible rays, endowed with marked chemical activity, are emitted (actinic).

Thus it is possible to settle by arranging the temperature what the shortest waves shall be, but no method is known by which the shorter waves can be produced without the longer ones.

That is to say, there is no means known of producing *Light* waves unaccompanied by *Heat*, or *Actinic* rays without one or both of the others (unless some of the recently discovered forms of radiation are of this character). Heat radiations must necessarily be given off by all substances, but what is required is a method for converting all the energy employed in any method of production into the particular set of radiations required.

The effect of increase of temperature on a substance which emits a line spectrum is such that the lines are found to become broader and less definite, hence, when fine lines are required, it is best to use as low a temperature as possible, and to avoid other electrical disturbance.

Wadsworth (*Phil. Mag.*, 41, p. 317) states that the finest lines known have a width

of $\cdot 01 \times 10^{-10} \text{m.}$, while lines such as H_{α} and D_{α} are about $\cdot 032 \times 10^{-10} \text{m.}$, even with the lowest temperature at which they can be produced.

The increase of intensity produced by an increase of the temperature was investigated by Tyndall, but his results deal rather more with *absorption* than production, and are hence dealt with on page 80.

The *total energy* emitted is a subject of great interest, but is unfortunately very difficult to estimate, if only from the difficulties of comparison and estimation; however, Wiedemann (*Phil. Mag.*, p: 261, 1889, 2) has attacked the question from the mechanical aspect, but his results are too elaborate to receive anything more than the barest mention here. He compares directly the increase of the total energy, and of the energy of the D_2 line for a sodium flame, and also for incandescent platinum on raising the temperature; his results show that sodium vapour has molecule for molecule 5,000 times the radiating energy of platinum.

Such investigations should help to show the way to reduce the enormous waste of energy in our methods of illumination, most of which

consist in using the heat produced by a chemical reaction, usually oxidation, to raise either the reacting, or some other substance to incandescence. The cause of luminosity in flames is still under discussion, and turns upon the necessity for the presence of solid particles in the flame.

A remarkable experiment showing the effect of temperature is that of heating the tube conveying the gas to a Bunsen burner, and thereby causing the flame to become luminous. This used to be taken as indicating that the increase of temperature of the flame was the direct cause of the luminosity, but obviously it is open to another interpretation.

Strictly speaking, a theory for the luminosity of flames is not necessary at all; there is no essential difference between heat and light radiation in themselves, and the difference that we recognise is only due to our possession of a sense organ which responds to radiation of particular wave lengths. It is perfectly conceivable that a person with an abnormal eye might be able to see what another person would call heat in the same way that sounds of very high

pitch are perfectly audible to one, and absolutely inaudible to another ear. Preyer's theory of colour vision starts with the assumption that the eye is a special localised development of the general sensibility to heat, which, in greater or less degree, is possessed by every part of the body.

Why under certain circumstances a particular set of radiation should be emitted by a flame is really only a small portion of a much larger question, viz. :—What is the ultimate mechanism by which the Ether is set vibrating, and to what is the difference in the wave lengths of these vibrations due ?

The Nature of the Substance. In all cases where the radiation can be examined accurately, it has been found that no two substances emit exactly the same combinations or series of waves ; for two substances at precisely the same temperature will emit infra-red waves of different characters and luminous waves of different colours.

It is stated by Tyndall that rock salt at a temperature of about 140° C. emits a monothermal vibration, while Rubens and Nichols

(*Phys. Rev.*, 4, p. 314) employ the radiation from quartz and fluorite, and remove all foreign rays by several reflections from plates of the same material. In this manner they produced waves for which $\lambda = 8.85 \times 10^{-6}$ m. and $\lambda = 24.5 \times 10^{-6}$.

But the production of a really *homogeneous* vibration has not been achieved, for the methods in use merely sift from a composite beam the one of the required nature, or get as near to this result as possible. Recent work¹ seems to show that the red Cadmium line approaches nearest to homogeneity since it has not been split up as have most of the other lines of the visible spectrum, and the remaining portions have not been examined to this degree of accuracy.

The sifting of the required portion of a composite beam away from the rest can be roughly accomplished by the selective absorption of certain substances. For instance, iodine solution absorbs all but the infra-red, glass and water nearly all but the visual. But by combining this with dispersion (see pp. 95 and 113), a far

¹ Michelson, *J. Phys.*, 3, p. 5, 1894.

more accurate result can be obtained, though the finite "width" of the spectrum lines mentioned on page 59 would put a limit to the possible separation.

Tyndall has made very careful investigations as to the quality and amount of the radiations which affect a thermopile, emitted by various substances when heated to the same temperature. The results given in the following tables are quite empirical, and are the relative deflections of his galvanometer; they are interesting as showing the great differences which substances exhibit, differences which may be looked upon as analogous to variations of colour.

Relative Radiations of Solids.¹

Elements.		Halides.		Sulphides.		Oxides.		Oxysalts.	
Phosphorus	38	rock salt	24·5	CaS	49·1	CO	62·5	ZnCO ₃	62
Sulphur	{ milk	25·8	AgCl white	25	ZnS	36·1	Fe ₂ O ₃	63·8	
	{ flowers	32·3	black	60	FeS	65·5	Fe ₃ O ₄	65·8	CuSO ₄
Platinum sponge	31·5	CdCl ₂	40	CdS	56·9	Pb ₃ O ₄	56·5	BaSO ₄	51·3
Lampblack	{68}	PbCl ₂	39	HgS	30·6	Sugar	52·1		
		CuI ₂	63						
		HgI ₂	26						
		PbI ₂	36						
		CdF ₂	48·6						

¹ Tyndall, *Experimental Researches*, p. 321.

The length of the radiating column has more influence with vapours than with gases, for the vapour molecules do not absorb the radiation emitted by themselves as much as the gaseous. This is largely due to the fact that the vapours were examined at $\frac{1}{60}$ atmosphere and the gases at 1 atmosphere.

Radiation from Vapours and Gases.¹

VAPOURS.			GASES.		
	13·1 in.	34 in.		13·1 in.	34 in.
Carbondisulphide	9	14·2	Carbon monoxide	16·6	24·4
Ethyl Iodide . .	19	38·8	„ dioxide .	17·5	23·3
Chloroform . .	19	41·0	Nitrous oxide .	22	21·7
Ether	36·5	68·0	Olefiant gas }	65	68
Formic ester . .	41·0	68·0	Ether }		
Ethyl borate . .	31·6	61			
p. = ·1 of an inch.					

Similar tables for the other supra-lacunal radiations would be useless, since the results are seen in a much more convenient form in the series of photographs of incandescent substances under various conditions, which

¹ Tyndall, *loc. cit.*, p. 191.

have been published by Hartley, etc. These show that while some substances, such as sodium, thallium, lithium, etc., emit comparatively few groups of waves, others, such as iron and palladium, emit enormous numbers of such groups.

To produce the ultra-violet rays in the most efficient manner, it is usual to raise certain substances to incandescence, while sunlight and the radiation from all incandescent bodies contain these rays, especially when the oxides of certain metals, such as zinc and magnesium, or of zirconium, etc., are used. Several flames are also rich in these rays, especially that produced when a mixture of nitric oxide and carbon bisulphide vapour is burnt.

The electric spark is a very rich source, even when employed as an arc discharge; and it can be improved by placing some zinc in the hollow of the lower electrode. Very short and brilliant electric sparks were however found by Hertz (*Electrical Waves*) to emit radiations differing in some of their properties from the usual ultra-violet rays (see p. 92).

The Con-
dition of the
Surface.

It will be convenient to consider under this heading the influence which the state of aggregation of the substance has upon the radiation emitted.

Substances can be divided into gaseous and non-gaseous ; for, while all gases give radiations consisting of *definite* groups which appear as lines in the spectrum, all liquids, when the radiation proceeds from their actual surface and not from the vapour, and all solids with the exception of the earth, erbia, give when heated a *continuous* series of rays which appear as a continuous spectrum. In rarefied gases the time of free translatory movement is great as compared with the time of internal oscillation of the molecules, and, although the latter are often *forced* by the frequent collisions, still they probably bear some simple relation to the natural time of oscillation of the molecules. Recent work has shown that in many cases certain lines in the spectrum bear the relation of harmonics to one another, and it is probable that many such relationships will be found in the visual and ultra-violet portions which can be photographed, and thus accurately measured.

The effect of an increase in density not only causes a very appreciable "thickening" of the lines, but seems (Humphreys and Mohler, *Astrophys. Journ.*, p. 114) to lower their frequency as a whole, though carbon vapour appears to be an exception.

The actual state of the surface of liquid and solid radiators seems to largely affect the emission of most rays, and it is particularly noticeable with calorific radiations, which are given off much more readily from bright, clean surfaces than from dull ones. It is for this reason that all exposed metal surfaces are made bright where the loss of heat is to be avoided, as in a calorimeter for instance; and it is supposed that the polished surface prevents the radiation from leaving it by the considerable internal reflection which obtains.

§ 3.—Detection and Recognition.

The ultimate end of all methods for the detection of ethereal vibrations is to make them appreciable by our organs of sense, and wherever possible by the eye as the only organ which supplies us with sensations susceptible of

being accurately measured, recorded, and compared.

Of the vast range of ethereal vibrations now known to us, only a very small portion (see p. 49) act directly upon the retina, and with the exception of *heat* rays none whatever act upon any other sense organs, so that the actual proportion of the whole range which are directly appreciable by us without the aid of some special device, is exceedingly small.

Of the various devices employed it will be seen from the following that almost every one appeals ultimately to the eye.

To detect the electrical waves Hertz used a wire ring with two terminals which, in his later experiments, were a soft metal point and a hard metal ball respectively, mounted so that the distance between them, which formed the spark gap, could be carefully adjusted. In order to concentrate the radiations and allow of their detection at greater distances than would be otherwise possible, the vibrator and resonator were each placed in the principal focal line of a large parabolic reflector.

The wire ring had to be tuned to the par-

ticular vibration employed, *i.e.* the wire had to be lengthened or shortened, and the shape of the circuit slightly altered until the maximum spark was obtained in any particular position.

With more refined and delicate modes of production, improved methods of detection became necessary.

The spark gap referred to above was replaced by such devices as the slit in a piece of tin foil,¹ the scratch on a silver film deposited on glass and other similar methods, the observation of the spark being often made with a microscope.

In place of the spark gap for large waves a vacuum tube (Dragonmis) was found very useful, but more accurate results have been obtained by observing the change of resistance in a conductor, or the alteration of an electro-static charge produced by the radiation.

For this purpose a fine wire connected either to a pointer² under a microscope, a sensitive

¹ Aschkenass, *Wied Ann.*, 3, p. 408. Mizuno, *Phil. Mag.*, 40, p. 497.

² Strinberg, *C. R.*, 122, p. 1403.

galvanometer (Fitzgerald), or an electrometer¹ has been used, and these have the great advantage of allowing sharp measurements to be taken.

An even more sensitive method seems to be the use of the coherer (Lodge), which consists essentially of a fine slit in some dielectric plate filled with metallic filings,² spirals,³ or other similar methods for obtaining a large number of imperfect contacts, the whole being treated as a variable resistance. A mixture of two liquids,⁴ such as mercury globules in paraffin, or water in oil can also be used ; the drops aggregating in the first case and precipitating in the second. The efficiency of this apparatus depends largely upon a careful adjustment between the electro-motive force used and the wave length of the vibration to be detected.

E. Rutherford⁵ has described a magnetic detector consisting of fine magnetised needles

¹ Gutter, *Wied Ann.*, xlix., p. 188 (1893), also Byerkness.

² Branly, *C. R.*, 111, p. 185 ; 112, p. 90.

³ J. C. Bose, *Phil. Mag.*, Jan., 1897.

⁴ Appleyard, *Proc. Phys. Soc.*, March, 1897.

⁵ *Proc. Roy. Soc.*, lx., p. 184.

surrounded by a selenoid. It is said to be very efficient and to be of the same order of sensitiveness as a bolometer. As they can be used longitudinally they are also useful for small amplitudes.

With these electrical methods of detection a single break given by a key is quite sufficient, thereby avoiding the troublesome induction coil (Bose).

Tschghaff (*Journ. Soc. Physico-Chem. Russe*, p. 115, 1890) has also made use of the bolometer for detecting these rays.

Supra-lacunal. The detection of the supra-lacunal waves cannot be treated in the same general manner, for the caloric waves are usually detected by their heating effects, which can be used either to cause an expansion of the fluid or solid employed, or by the change of electrical condition of a conductor.

The first method is employed in the various modifications of the thermometer, which are all comparatively rough for this purpose, though Joule (*Proc. Manch. Lit. Soc.*, iii., 73) employed the movement of heated air to detect the radiations from the moon.

A helix of ebonite with an attached mirror has been used by Michelson (*Journ. de Phys.*, i.) 183) for which its high coefficient of expansion makes it very suitable, and also by Edison in the *Tasimeter* (*Teleg. Journ.*, Nov., 1878) where it makes a variable contact with a piece of carbon, this apparatus being able to detect easily the radiation from a gas jet 100 feet away.

The *radiometer* has been used recently by Nichols (*Phys. Rev.*, 4, p. 297), who finds that it is free from magnetic or thermo-electric disturbances, and also from air currents, but the necessity for a window depending on the radiation and the frequent exhaustion required, are serious defects.

The *micro-radiometer* of H. F. Weber (*Archiv. d. Genève*, 1887, p. 347) consists of two columns of zinc sulphate, forming two arms of a Wheatstone's bridge, their length being varied by a differential thermometer; while in the *Bolometer* of Langley (*Proc. Am. Acad. Sci.*, xvi., 342) a platinum resistance of extreme delicacy is employed, and many precautions are taken to avoid extra-

neous changes of temperature. With this instrument Langley has recorded changes produced by the radiation from the fixed stars.

The classical researches of Melloni and Tyndall were performed with a *Thermopile*, depending on the production of thermo-electric currents by change of temperature; the order of these is however small, and consequently much delicacy could not be expected, and this was further reduced by the large mass of metal to be affected. By taking a single thermo-electric couple and suspending it in a magnetic field, it acts as its own galvanometer, and responds instantly to minute changes of temperature; this arrangement has been used by Boys, in his *radio-micrometer*, in which a soft iron screen encloses the whole and prevents outside influences, except those which enter through the proper opening.

Minchin (*Proc. R. S.*, 1896, p. 233) has so far improved his selenium cells (*see* p. 142) that they can detect and measure stellar radiation, and he estimates that of Procyon as equivalent to 116 billion billion candles.

The energy of luminous and actinic rays

is small, and hence they affect the instruments mentioned above only to a small extent, while the physiological detection of light by the eye far exceeds any of them in delicacy.

Although chemical actions are principally shown by the so-called "actinic" rays, yet luminous and calorific rays will produce similar changes (p. 147) under certain conditions, so that there is no valid distinction between rays which do, and which do not, produce chemical change, excepting one of degree.

The change of frequency produced by absorption such as gives rise to calorescence or fluorescence (*q. v.*) also brings the infra-red and ultra-violet rays more into notice.

§ 4.—Penetrative Power.

The different electro-magnetic vibrations differ in their power of passing through the same kind of matter, and the same radiation experiences different degrees of difficulty in penetrating various classes of substances. While every known substance modifies a heterogeneous radiation by what is known as "selective absorption."

The amount of absorption is found to depend upon—

- | | | |
|---------------------------------|---|--------------------|
| I. The frequency | } | of the radiation. |
| II. The amplitude | | |
| III. The duration of the action | | |
| IV. The nature | } | of the substances. |
| V. The orientation | | |

The last named is only observable with polarised vibrations, and is treated under Dichroism (p. 129). The process of absorption consists in a diminution of the intensity in the energy of the vibration. It takes place in such a way that, supposing the latter homogeneous, *the amount transmitted by any substance decreases geometrically as the thickness increases arithmetically*, so that if α is the fraction transmitted by unit thickness (the coefficient of transmission), I is the initial intensity and I' the intensity after transmission through a thickness of x units, then $I' = I\alpha^x$.

**Influence of
Frequency.**

The penetrative powers of radiations of widely different wave length for the same substance is perhaps not so much influenced by the conditions given on page 77,

as by the fact that very long waves rarely travel through a thickness of material which is comparable with a wave length, while light waves, for instance, excepting in certain cases, must traverse a thickness comparable with several wave lengths.

Thus long Hertzian waves have been found¹ to traverse half a mile of a closely built town, but the actual thickness of material traversed was probably not great compared with the length of the waves which were used.

These waves, when of the order of $10^2 m$, easily traverse those metallic sheets which are non-radiable to waves of the order of 1 metre, and it is noticed that in cases where the frequency is increased by mechanical means that the radiability of a given material decreases.

Helmholtz' theory assumes that absorption by substances is due to the rapid damping of the incident vibration by resonance; that is to say, that those vibrations will be absorbed whose frequency corresponds to the times of vibration of the molecular aggregates, molecules, atoms, ions, or of the electrical charges

¹ Rutherford, *loc. cit.*

on the ions as the case may be, and since there are these several possibilities, we should expect to find that substances exhibit more than one main absorption band over the whole range of vibration, and in general this will be found to be the case.

As the coefficient of transmission is different for different frequencies with the same substance, it is clear that an increase of thickness must alter the relative proportions of the constituents of a heterogeneous radiation, and hence, that where this includes light waves that there will be a change of colour. Perhaps the best example is cobalt glass, which is blue in thin and red in thick layers, owing to the much higher coefficient of absorption for the blue rays.

Assuming that Kirchoff's law is applicable, it should be possible to calculate from the total energy emitted by a body, if that can be obtained, the thickness which would be non-radiable to that vibration at least.

Wiedemann has estimated the total energy radiated by the sodium lines and by incandescent platinum, as far as this can be estimated,

and gives¹ it as 1.1×10^4 and 2.2×10^4 ergs respectively, and since platinum of 10^{-5} cm. thick, one square centimeter of which weighs 2×10^{-4} grams, is opaque, it follows that 4×10^{-8} gr. sodium should be: a somewhat remarkable result.

Influence of Amplitude. It is a matter of common knowledge that a more intense radiation will penetrate a greater thickness of a substance than a less intense one, and it also appears that in many cases with heterogeneous radiations of varying intensities, that the emergent beams will have different compositions and relative intensities. This has not yet been observed with infra-lacunal waves, nor with any other than Tyndall's "heat waves" and with light. It has been shown that the intensity of the infra-red rays from a source emitting light (obscure rays) is greater than those from one at too low a temperature to do this (rays from an obscure source of heat), and Tyndall found that the former always possessed a far greater power of penetration.

The following tables show some of Tyndall's

¹ Mechanics of Luminosity, *Phil. Mag.*, p. 263, 1892.

results, of which they are merely a small selection. Some are quoted by him from Melloni (*La Thermochrose*, p. 164); they can be only very approximate, as a thermopile and galvanometer were used, and no attempts were made to obtain an even approximately simple radiation. The numbers given represent percentages transmitted or absorbed.

Solids, percentages transmitted.

	Blackened at 100° C.	Copper 390° C.	Incandes- cent Platinum.	Locatelli Lamp alone.	through alum.
Fluorspar . .	33	42	69	78	90
Potass bichrome	0	15	28	34	97
Alum . . .	0	0	2	9	90
Ice	0	0	0	6	

Liquids, percentages absorbed.

	HYDROGEN FLAMES, With Plati- num Wire.		Without.	Red-hot Platinum.
Carbon bisulphide . .	14		27.7	12.5
Ether	78		92.6	76.1
Water	93.6		100	88.8

Vapours, ditto.

	Lamp-black at 100 C°	Barely visible.	PLATINUM.		
			Red.	White.	Intense.
Carbon disulphide	9·3	6·5	4 7	2·9	2·5
Ether	47·5	43·4	31·9	25·9	23·7

These results naturally depend on the thickness employed, and it is possible that with thicknesses which are proportional to the intensities that the emergent beams might be of much more equal value.

Since the effect of both variations of frequency and amplitude would be included in the above observations, and no attempt is made to separate the parts which are due to each, it is difficult to find equivalent cases with light; for it is not only the change of "colour" which has been observed, but also of the intensity.

A change of colour in the light transmitted by a substance does not seem to occur with a variation in the intensity of the incident beam in any known case, unless the thickness is altered, when it is discussed on page 78.

The Influence
of Time.

This factor has not been systematically investigated, but it is probable that it exercises a greater influence than is commonly supposed. It would be expected that in certain cases the initial velocity of the radiation might be largely reduced, and hence that the progress through a substance might be comparatively slow ; Edison mentions that light enters a fluorite crystal at a visible rate, but no measurements were given.

The Influence
of the
Substance.

The line of demarcation between conductors and dielectrics is really arbitrary, and hence we should expect to find all gradations from great *non*-radiability to great *trans*-radiability in existing substances, making any marked distinction somewhat invidious, so that they can be best treated as if they were more or less marked deviations from the perfect conditions.

As stated before, a perfect conductor would be absolutely non-radiable even in the thinnest *possible* layers, since it would reflect the whole without loss, while all known substances in the thinnest obtainable layers transmit some vibration, absorb some, and reflect the rest.

The process of absorption may not result in more than an increase of temperature, which, if not very great, will have no permanent effect ; while it may cause an alteration in either the substance, or the radiation, or possibly in both. When such changes occur we should expect that the absorption (for the particular radiations which produce them) would be of a different character to that which is found where they do not exist, while with other radiations the absorption would be quite normal.

As would be expected, substances show enormous variations among themselves in their radiability, but the great influence of small variations in the substances themselves makes the whole question very complicated.

The physical condition of the substance is most important with the shorter waves, for it is clear that turbid or discontinuous media would give a radiability which was of far too low a value, since a large proportion of the incident radiation would have been internally reflected, and it seems possible that many seemingly irregular cases would be found to be largely due to a suspension of small non-radiable

particles in an otherwise trans-radiable substance.

The magnetic permeability of the substance has a marked influence with the infra-lacunal waves, but apparently none with those of the rapidity of light; among the slower waves a considerable variation is observable, for while iron and copper show radiabilities of about the same order for waves of a few centimeters in length, with those of many miles iron is very non-radiable and copper very much less so.

It is only with substances that are definite compounds, and either amorphous or simply crystalline, that any definite conclusions can be drawn, though observations on less simple bodies may be of great assistance.

Few cases are known up to the present in which selective absorption has been observed for infra-lacunal waves, probably because their free period is much greater than that of any molecular aggregates that they could encounter, and because of their wave length (*see* p. 102). A variation has, however, been found by Drude (*Wied Ann.*, 61, 1, p. 1), who gives the following co-efficients :—

Frequency 70×10^{10} per sec.	Water	·27
„ 25 „ „ „	„	·50
	Amyl alcohol	·51
	Ethyl alcohol	·21
	Acetic acid	·23

while Plank (*Sitz. Berlin*, p. 289, 1895), has shown that by causing these waves to fall upon an oscillator of corresponding period, they can be very rapidly damped, which is analogous to what occurs with molecules.

The supra-lacunal waves may be divided up by their varying penetrative powers into several classes although these are really quite continuous, still sufficient differences are shown to make the division quite reasonable.

Thus the long "heat" waves of Pictet (p. 58), and of Rubens and Nichols (p. 63), which are of the order of ·25mm., were found to traverse such normally athermanous substances as wool and cotton with ease, while vitreous silver chloride, and lampblack, both opaque substances, transmitted 70 and 90 %s respectively, showing that for these rays the latter is not a "black" body. Such diathermanous and transparent substances as rock salt and silvite only trans-

mitted 3 and 5 %s, while 2 mm. of fluorspar was absolutely nonradiable.

The absorption of the more rapid supralacunal radiations is a matter of every-day knowledge ; for although a considerable portion of the heat and light from the sun is reflected from most substances, yet it is so modified by selective absorption in the small depth to which it penetrates, that the temperature of the substance is raised and the light appears to be coloured in the majority of cases.

The "Heat" or infra-red rays of Tyndall and Melloni, which includes all those between the last mentioned and the limit of the visual spectrum, have been largely investigated but not by the more recent methods, so that the results must be somewhat vague. A few data for solids and liquids are given on p. 80, while the following table gives some of Tyndall's results with gases, and shows that those with more complicated molecules, and especially those which suffer a contraction on combination, are the more energetic absorbers, such substances as ozone and certain perfumes exhibiting a marked effect even when present in small quantities.

	Air.	Oxygen.	Nitrogen,	Hydrogen.	Chlorine.	Hydrogen.	Chloride.	Bromine.	Hydrogen.	Carbon
	Hydrogen.								Bromide.	Dioxide.
1Æ	1	...	39	...	62	...	—	...	—	90
$\frac{1}{30}$ Æ	1	...	60	...	—	...	160	...	1005	970

	Nitrous Oxide.	Hydrogen.	Sulphur			
		Sulphide.	Dioxide.	Ethylene.	Ammonia.	
1Æ	355	...	—	...	1710	...
$\frac{1}{30}$ Æ	1860	...	2100	...	6480	...

Common experience supplies many cases of substances which are very athermanous and transparent, such as glass, which also exhibits a selective absorption among the infra-red rays, for it is known that glass will transmit easily the heat rays from the sun, while it is more athermanous to those which are reflected from the ground. The converse is also of frequent occurrence, well known cases being iodine solution, india-rubber and ebonite, for Abney has shown that the two latter transmit a very large proportion of the rays from $\lambda = 10000 \times 10^{-10}$ to $\lambda = 5000 \times 10^{-10}$ and from $\lambda = 7500 \times 10^{-10}$ to $\lambda = 1200 \times 10^{-10}$ respectively, going down to 15000×10^{-10} with the arc light in the case of ebonite, which also showed an absorption coefficient of 1·8 for a $\frac{1}{84}$ -inch plate.

With the luminous rays, as before mentioned, the changes are far more easily detected and measured, for, by observing their intensity and colour, either by eye or with a spectroscope, the whole change due to absorption can be accurately measured.

The dependence of colour on atomic weight is not in general shown, and although the halogens are successively pale green, green, red, and violet, even here the colour is not due to the atoms (for they all form salts which are colourless in solution), but to the molecules or molecular aggregates; however, iodine vapour at high temperatures, when it certainly consists of single atoms, is still violet. There is no doubt that the aggregation of atoms of the same kind tends to lower the frequency of vibration in the molecule; this is well shown by investigating the absorption bands, but is not always quite apparent from the change of colour, as when *red* NO_2 condenses to *yellow* N_2O_4 . The weighting of molecules so that they will absorb radiations of a slower and slower frequency has been successfully accomplished with many dye-stuffs, by altering the

molecular weights of the side chains, and in this manner an absorption band originally in the violet has been brought completely through the spectrum.

The opacity of the metals does not seem to be due to any property of the atoms as such, for the solutions of their salts are never as opaque as would be expected from their strength. The Iron, Gold, and Platinum groups contain those metals which give the principal coloured salts, while the two highly coloured metals, gold and copper, belong to the same group, and from the fact that silver and gold transmit red and green, and reflect bluish white and yellow light, it seems possible that each exhibits a definite absorption band.

Certain linkings of atoms appear to endow the substance with much greater and more marked absorptive powers than other nearly allied groups. For instance, when nitrogen atoms are combined as in the azo ($-N=N-$) or amido ($=N\equiv$) groups they are highly absorbent, while as nitro (NO_2) or cyano (CN) groups they exert little effect, the same is true of hydroxyl oxygen ($-O-H$) as opposed to

carbonyl oxygen ($=C=O$) (Zsigmondy, *Wied Ann.*, 87, p. 639).

Definite relations can often be found between the frequencies of the radiations absorbed, sometimes as simple as 1:2 as with silver bromide, while Abney and Festing have shown¹ that in liquids containing Carbon, Hydrogen, and Oxygen, the bands terminate at the lines belonging to these elements.

Simple gases and vapours produce an absorption which consists in the removal of certain definite waves almost completely, while increased molecular complexity results sometimes in the absorption of a large number of consecutive rays entirely, and at other times only partially.

If the transmitted radiation is then subjected to dispersion and examined, it is found that the spectrum produced is linear for simple gases, but becomes banded for the more complex, that usually for liquids there are wide absorption bands which cut out entire groups of rays, and that solids only exhibit this latter case.

¹ *Proc. Roy. Soc.*, Feb. 10, 1881.

In those cases in which it has been tried experimentally, Kirchoff's law is found to hold good, viz., that bodies absorb most readily the radiations they would themselves emit.

Ultra-violet radiations exhibit differences among themselves as marked as those which separate them from the visual rays, and many transparent substances, especially when crystalline, are more non-radiable to these than to the visual rays. Such are glass and water, while the highly coloured chromates form a marked exception (Agafonoff, *C. R.*, 123, p. 490), and air which is very trans-radiable to all radiations of a wave length of more than 1500×10^{-10} m., but becomes very much less so to waves shorter than this (Müller, *Wied Ann.*, 58, p. 771).

Since the ultra-violet rays are those which exert the most powerful photo-chemical action, we should expect to find the case mentioned on page 232 most clearly shown with these rays.

Such phenomena have been observed, and it would be expected that all substances which can be affected by the rays would be more non-radiable to them before they had been

thus affected than after, but photographic emulsions do not appear to give the desired result, though they would seem to be the most likely instances. However, a mixture of chlorine and hydrogen gases is less radiable than equal quantities of the two successively to ultra-violet rays, though no difference could be observed when red rays were used.

The following list of relative opacities is due to Hertz, when he was using very rapid ultra-violet radiations, but the frequency was not observed (electrical waves).

Trans-radiable.	Bromine, Potassium Water, Sodium Silica, Magnesium Calcium	} Sul- phates.
Intermediate.	Mineral Acids, Ammonia Solution, Ether, Alcohol, Sugar, Alum, Rock-Salt.	
Non-radiable.	Glass and Metals, Coal Gas, Nitrogen Dioxide.	

These results show that while glass keeps non-radiable at this frequency, water does not ; hence they give a superior limit to the upper absorption band of the latter.

Fluorescence. A difference of frequency between the incident and emergent radiations with any substance may be produced, either by the occurrence of vibrations in the substance which nearly coincide with those of the incident radiation, and thus produce forced vibrations of a different period, or the incident beam may be entirely absorbed, the substance then becoming a source of a more or less different vibration. It is probable that no real distinction is to be drawn between these cases, and that both result from the synchronism between the frequency of the radiation and of some vibration in the substance; the change may either be of increase or decrease of frequency, though the latter is the more usual.

The lowering of the frequency of certain ultra-violet radiations so as to bring them into the limits of the visible spectrum was first observed by Brewster (*Phil. Trans.*, 1848) for alcoholic chlorophyll, and by Herschel (*B.A.*, 1848) for dilute solutions of quinine sulphate, and subsequently Stokes (*Phil. Trans.*, 1852) brought forward a complete explanation of the effects observed. Many substances exhibit the

phenomenon at ordinary temperatures, crystals such as fluorite, etc., or solutions of carbon compounds such as fluoresceïn and thalleen, or colloids such as uranium glass and many sulphides; it has also been found that the most favourable conditions are those of solid solution.

That the incident radiation is really completely absorbed in many cases is shown by the intimate connection between Fluorescence and Phosphorescence; in the latter case the vibrations induced in the substance having sufficient energy to continue radiating, even after the exciting cause has ceased.

Dewar has observed that at temperatures about that of the boiling point of oxygen, *i.e.* -184° C, all bodies become phosphorescent, even living tissues (*Phil. Trans.*, 1895).

Many biaxial crystals which show fluorescence emit it in a polarized condition, and it is noticed that in this case the thermo-luminescence is also polarized, but liquids never give a polarized radiation (Schmidt, *Wien Ann.*, 60, 4, p. 740).

§ 5.—Reflection and Refraction.

For convenience in the consideration of the reflection and refraction of wave trains, it will be best to treat each portion of the wave surface as if it had a separate existence and had been propagated from the source as a narrow pencil or *ray*. When such a ray encounters a surface of separation between two media, A and B, it is usually partially *reflected*, and partially transmitted, and when the incidence is not normal the latter portion is deviated from its course or *refracted*.

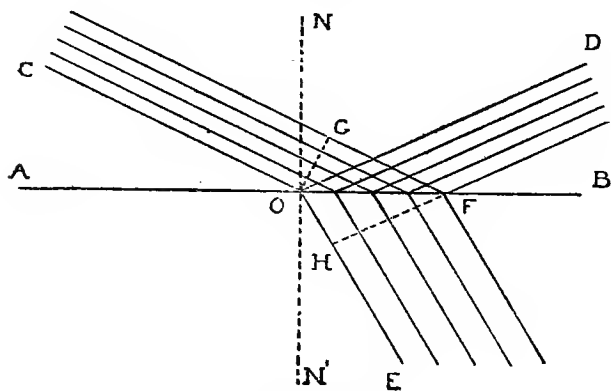


FIG. 3.

It is found, experimentally, that the reflected

and refracted rays remain in the plane which contains the incident ray and the normal to the surface, and that the angle of incidence $\angle CON$ (i) Fig. 3 is equal to the angle of reflection $\angle NOD$.

The ratio of the sines of the angles of incidence (i) and refraction $\angle NOE$ (r) is also found to be a constant, and is known as the relative *refractive index* (n). This quantity is the inverse ratio of the relative velocities in the two media, or

$$n = \frac{\sin i}{\sin r} = \frac{OH}{FG} = \frac{V_1}{V_2}$$

The reflection of *light* from surfaces, especially when metallic, has been known for centuries, and probably that of heat for some considerable time, together with their refraction through lenses, but prismatic refraction and the decomposition of white light was first observed by Sir I. Newton in 1666.

It is clear that the reflected or The Reflected Ray. transmitted rays will have a reciprocal relationship, and we may expect to observe anomalous reflection in cases where

the refractive index for the particular radiation is very anomalous.

A most curious case has been recently investigated,¹ which shows that the usual ideas about reflectors are by no means correct. Quartz is found to transmit nearly the whole of a radiation of a frequency of 4054×10^{10} ($\lambda = 7.4\mu$) more than any known substance does for visual rays, while at 3571×10^{10} ($\lambda = 8.4\mu$) the reflected wave is more than 99.5 % of the whole, the substance being then an almost perfect reflector.

Partial reflection and transmission will only occur at *all* angles of incidence when the first medium is of less density than the second; when the reverse is the case there will be no transmitted wave when the angle of incidence reaches a value which makes the angle of refraction 90° , *i.e.* when $\sin r = 1 = \sin i \times n$.

This is not strictly true for the whole electromagnetic series or for all substances, since those substances which exhibit anomalous dispersions will show the converse effect with certain frequencies, while Kundt (*Phil. Mag.*, 1888)

¹ Nichols, *Phys. Rev.*, 4, p. 297.

has shown that a few metals refract a ray *away* from the normal, and hence that they would exhibit total reflection from this cause alone.

The electro-magnetic theory shows that a perfect conductor would completely reflect rays of all frequencies at all angles of incidence, for in such a substance, as has been shown, the electric-elasticity $1/\kappa$ must be zero, and hence no transmitted wave is possible.

All existing substances, however, even the best conducting metals, are somewhat trans-radiable, and the relation between the reflected and transmitted waves depends on the nature of the substance and the condition of its surface in a manner which is not properly understood.

In what has been stated above it has been supposed that the reflection takes place exactly at the surface, and that the vibration is unchanged by it; but this does not appear to be the case, for Hertz (Electrical waves) found, when using stationary waves (see p. 112), that the first node, instead of being $\frac{1}{4}\lambda$ from the surface, was less than this, and hence that the real position of reflection was a few centimeters *behind* the surface, instead of on it.

The reflection of light from certain substances has been found to result in a reversal of phase which can be detected by interference (see p. 110), while a silver surface was found by Edser and Stansfield (*Nature*, Sept., 1897,) to produce a retardation of $\frac{3}{4} \lambda$.

The relative *densities* of the two media clearly affect the refraction The Refracted Rays. largely, as has been shown above, and it has been supposed that a variation in the density of one of the media would cause such a variation in the refractive index to a given radiation that some relation between them would remain constant. The two most in favour are $n - 1/\rho^{(1)}$ and $n^2 - 1/\rho$, the following data show that neither are adequate when a sufficient range of densities is considered. However either formula gives a conveniently approximate connection in many cases when a comparison is made between substances in the same *state* but neither is trustworthy when this is different.

The refractive indices and densities of a

¹ Gladstone & Dale, *Phil. Trans.*, 1858 and 1863.

² See Everett's C. G. S. tables.

number of elementary bodies are given in the following tables from Landolt and Börnstein :—

Element.	N_D	Observer.	ρ	Remarks.
Hydrogen	1'000139	Lorenz	'00008837	liquid at BP
Carbon. .	2'470	Schranz	3'52	
Nitrogen .	1'000296	Lorenz	'0012393	
	1'2053		'89	
Oxygen. .	1'000272	"	'0014107	liquid at -185°C
	1'225			
Magnesium	0'370	Drude	1'74	
Phosphorus	2'14	Gladstone & Dale	1'83	
Chlorine .	1'000773	Frascart	1'47	Knightsch Lieb. Ann., 1890
Iron. . .	2'36	Drude	7'86	
Cobalt . .	2'76	Du Bois & Rubens	8'6	
Nickel . .	1.84	"	8'9	crystalline soluble in CS_2 electrolytic
Copper. .	0'641	Drude	8.92	
Zinc. . .	2'12	"	7'15	
Selenium .	2'98	Sirks	4'5	
Silver . .	0'181	Drude	10'53	
Cadmium .	1'13	"	8.60	
Tin . . .	2'10 liq.	"	7'025	
Platinum .	2'06	"	21'50	
Mercury .	1'73	"	13'55	
Thallium .	1'75	Gerchun	11'85	
Lead . . .	2'01	Drude	11'37	

The frequency. The relation between the frequency of a vibration and its index of refraction by a substance was the subject of one of

v. Helmholtz's most brilliant investigations,¹ and although some important writers² have found apparent inconsistencies in certain portions, still on the whole it is generally accepted as the best and most complete treatment of the subject.

For perfectly trans-radiable substances he gives the equation,—

$$n^2 = \frac{\nu^2 + \frac{1}{m} - N^2}{\nu^2 - \frac{1}{m} - N^2} = \frac{\alpha^2 - N^2}{\beta^2 - N^2}$$

Where ν is the value of the frequency N when the period of the oscillations in the radiation agrees best with that of the ions of the substance, and m is the mass of these ions. Values calculated from this agree well with experimental results in the visual spectrum for some very slightly absorbent substances such as turpentine, but would not hold over any range of frequencies.

A curve plotted from such values is shown in fig. 4, at A , together with one illustrating the variation, when the friction co-efficient (k) is considered, for the values $\alpha = 5$, $\beta = 4$, $k = 0.1$.

¹ *Wied Ann.*, xlviii., pp. 389 and 723, 1893. Translated in *Electrician*, xxxvii., p. 404.

² See O. Heaviside, *Electrician*, xxxvii., p. 470.

f g represents the normal case with slight absorption and normal dispersion.

At *l*, where $N=\beta$, the curve makes a cusp high up the axis of ordinates.

b i represents the case where we have still a refractive index greater than unity, but

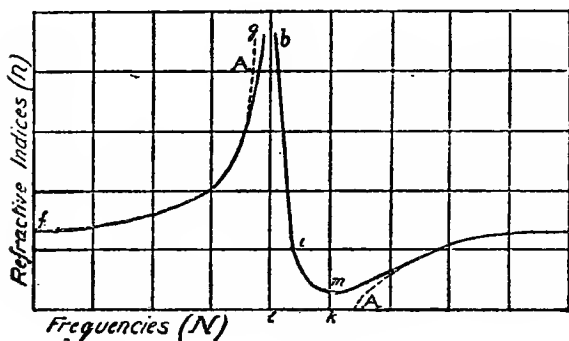


FIG. 4.

marked absorption and anomalous dispersion, this region being that of an absorption band.

i m represents a portion where the refractive index is less than unity, accompanied by absorption and anomalous dispersion. Kundt has found this case with certain metals.

At *k*, where $N=\alpha$, the curve takes an upward turn, and for most of its way represents

cases where the index is less than unity; but the absorption is small and the dispersion normal, the index approaching unity as the frequency increases. Silver, copper, and gold represent such cases, and possibly many more may be known, see Part iii., page 267.

The refractive indices of water and alcohol have been investigated for many frequencies, and show the variation well.

Water, $\kappa = 80.87$, Heerwagen. Alcohol, $\kappa = 25.8$, Tereschin.

Frequency.	n^2 .	Observer.	n^2 .	Observer.
Small	80.9	Heerwagen	25.9	Nernst
"	80	Nernst	25.5	Tereschin
25×10^6	79.4	Thwing	24.8	Thwing
60 "	79.4	Cohn & Zeemann		
150 "	80.6	Drude	24.4	Drude
400 "	81.67	Mazotto		
650 "	81.60	Drude		
800 "	83.6	"		
6,000 "	77.44	Cole	10.2	Cole
37,500 "	80.45	Lampa	6.8	Lampa
50,000 "	88.45	"	5.3	"
75,000 "	90.23	"	5.0	"
7.5×10^{10} }		"		
509,000 "	1.74 (15.25)	Baille	1.83	Ketteler

The results for water show a rising curve for the whole of the infra-lacunal waves, and probably show the part before the great absorp-

tion band which is known to exist in the infra-red rays. Since water vapour, and also water, is highly non-radiable for ultra-violet rays, it appears that there are two principal absorption bands. The results for alcohol do not show evidence of any such absorption within the frequencies measured.

Drude has found that the refractive index of water is simply proportional to the temperature between 0° and 26°C. , the coefficient being -0.367 for a frequency of 0.4×10^{10} ; for sodium light it is more complicated, but of the same sign.

The dispersions of other substances have not been measured systematically over the whole range of vibration, but the following tables show some results which have been obtained by various observers :—

Quartz.

λ	n	Authority.
infinite	4.5	Landolt's Tables
(a_{10}) 8070×10^{-10}	1.378	
(D) 5896 "	1.434	
(Al_{32}) 1856 "	1.509	

Rock Salt.

λ	n	Authority.
85000×10^{-6}	3.05	von Lang ¹ Rubens & Trowbridge ²
223000×10^{-10}	1.34	
142000 "	1.437	Dursand Rubens & Snow ³
86700 "	1.503	
5896 "	1.514	
2573 "	1.544	
	1.585	

Glycerine.

N	n	Authority.
133×10^6	6.24	Drude von Lang
400 "	5.04	
35.3×10^8	3.84	
3.74×10^{10}	1.84	
75 "	1.62	
39450 " (A)	1.467	Landolt's Tables
76280 " (H)	1.386	

In the region of the visual rays, Rubens and Snow (*loc. cit.*) have found the index of rock salt increases with the wave length, while in the above table it decreases. They also find

¹ *Sitzungsberichte Wien*, 105, p. 253.

² *Wied. Ann.*, 60, 4, p. 724. ³ *Phil. Mag.*, 35, p. 35.

the same occurs with sylvite and fluorite, but state that these substances show a very large dispersion with the infra-red rays, although there is little absorption or dispersion with the visual rays. The above results for water and quartz show that there is a marked anomalous dispersion in the lacunal region.

The infra-lacunal waves are all capable of refraction if the right material is used, and in many cases a refracting substance can be built up, so to speak. Thus a series of resonators arranged in a prismatic form have been employed.

The concentration by cylindrical lenses of rays about one meter in wave length was accomplished by Lodge, and he was thus enabled to get a parallel beam. The first workers used pitch, following Hertz's example, but subsequently sulphur has been employed, the method of observing the index of refraction being usually that of simple refraction and observation of the position of minimum deviation; but Bose has found the method of total reflection the most efficient, on account of the sharp reading which can be obtained.

For this purpose half-cylinders are employed with a diaphragm between their plane surfaces, the focal length of the cylinder being determined by a rough preliminary observation of the wave length, and the oscillator being then placed in its principal focus.

In no substance at present investigated has an abnormality, which would give the infralacunal rays a less refractive index than the light waves, been observed, while it is a well known fact that usually the heat focus of a lens is further from it than the light focus. Many substances are known in which marked absorption bands occur for light waves, and some of these show an anomalous dispersion. It is observed that substances which give this effect possess a strong surface colour,¹ especially noticeable, for instance, in alcoholic solution of fuchsine² (rosaniline hydrochloride). In this the surface colour is green, this colour being entirely absent from the transmitted ray ; while the violet is the *least* refracted, and the whole spectrum is elongated to an enormous extent.

¹ Kundt, *Pogg. Ann.*, 1871.

² Christiansen, *Pogg. Ann.*, 1870.

**Double
Refraction.**

The phenomenon of double refraction consists of the division of the transmitted vibration into *two* wave surfaces, which in general have different forms and travel with different velocities.

The simple refraction that has been previously considered is the result of a spherical wave surface; and in all cases where a section of the wave surface, at right angles to the direction of the ray, is circular, the refraction is simple. This can only occur when the elasticities are equal in all the radial directions round the path of the ray, such as obtains in crystals of the regular system and in other isotropic substances, and along certain lines, in crystalline substances belonging to other systems.

Uniaxial crystals possess *one* such line or axis, which is, as a rule, simply related to the crystallographic axes. Biaxial possess *two*, and give rise to a complicated arrangement of wave surfaces which *cut* one another. Among the best known are mica, selenite, prismatic sulphur, and many isotropic substances when in a state of mechanical or electrical strain.

In general, a vibration travelling in any other direction than along the optic axis is divided into two. One of these is found to obey the *ordinary* law of refraction; hence its wave surface is a sphere. The other, or *extraordinary* ray, gives a refractive index μ_e , which varies with the direction of the ray; either its minimum or its maximum value coincides with the ordinary index.

In negative crystals such as calcite, tourmaline, apatite, μ_e is less than μ_o , and the wave surfaces are an oblate spheroid inclosing spheres. In positive crystals such as ice, quartz, zircon, μ_e is greater than μ_o , and the wave surfaces are spheres inclosing prolate spheroids.

Many substances have now been shown to possess this property for the infra-lacunal waves, notably wood and vulcanite,¹ when coated on one side with tin foil so as to render it anisotropic. Rhombic sulphur with waves of $\lambda = 6\text{ mm.}$ gives two well-marked indices corresponding to two dielectric constants—

$$\sqrt{\kappa} = 2.18 \qquad n = 2.2$$

$$\sqrt{\kappa} = 1.95 \qquad n = 2.0.$$

¹ von Bezold, *Wied. Ann.*, 54, p. 572.

It is possible to make a Nicol's prism¹ (p. 121) of sulphur with a vulcanite plate in place of the Canada balsam, and also a quarter wave-plate, which will give all the polarization phenomena.

Unequally chilled paraffin is found to reproduce for these rays the well-known double refracting properties of unannealed or strained glass.²

§ 6.—Interference and Diffraction.

The term interference is only used here for vibrations which may be treated as collinear, and in such it is necessary that the two interfering rays shall be portions of the same vibration which have been caused to suffer by some means a relative change of phase.

A very usual method for producing this is to cause the two rays to traverse slightly different paths as shown in Fig. 5, where a radiation AB is incident upon a screen with

¹ Lebedew, *Wied Ann.*, 56, p. 1, 1895; Translated in *Electrician*, 36, p. 92.

² J. C. Bose, *loc. cit.*

two small openings which permit the rays AP and BP to meet at some point P. These rays leave A and B in the same phase and arrive in the same phase at P if the distance $BP - AP = n\lambda$, an even number of half wave lengths; and in an exactly opposite phase

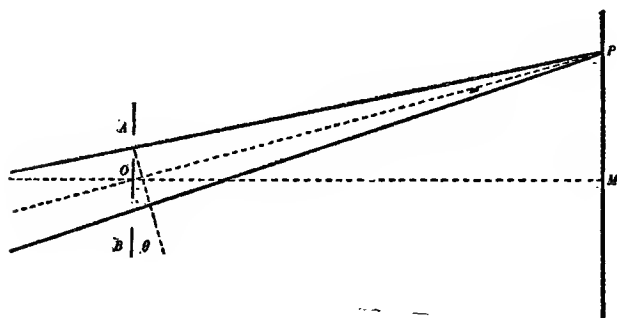


FIG. 5.

if this distance $= \frac{2n+1}{2}\lambda$, an odd number of half wave lengths. Thus as P travelled from O it would successively take up alternate positions of minimum and maximum intensity. Besides such a method, interference is produced by reflecting a radiation at grazing incidence

from a mirror (Lloyd, *Trans. Irish Acad.*, Jan., 1834) and also from two mirrors placed, at an angle of nearly 180° (Fresnel, *Œuvres*, I, p. 703), while it is constantly produced between the rays reflected externally and internally from thin layers of partially radiable substances.

By the interference of two wave trains of equal amplitude and in opposite directions, stationary wave forms are produced as is the case with material vibrations. Such a method has been frequently employed to measure the wave-length of the Hertzian waves, while an example in which it was used for light is mentioned on page 99.

Instead of producing a difference of phase by a difference in the *distance* traversed by the two rays, it is frequently convenient to employ the change of velocity produced by different media, which change being a measure of the refractive indices of the media can be frequently used to measure these. For this purpose a plate of the medium to be examined, of thickness e and index n , is placed in the path of one of the rays in such an arrange-

ment as is shown in Fig. 5, and in which x maxima are observed in O P before its introduction, and x' after, then $e (n-1) = (x-x')\frac{\lambda}{2}$ which gives either e or n if the other quantities are known.

Many cases of interference have been investigated for the various types of rays, and all seem to show that the whole series would behave in an exactly similar manner. It is from this constant nature of the phenomenon that it is most useful for determining the wavelength of any vibration.

Diffraction is produced by the mutual interference of the different wavelets resulting from a single wave, and is observed at the edges of the shadows cast by non-radiable bodies to a radiation from one source, the phenomenon being independent of the form and degree of finish of the edge. Suppose that A, Fig. 6, is a straight edge of the plate A B and that O is the point of emission of a radiation of which S R A is the portion of a wave surface.

The effect at P will be due to a small

number of elements only round R , so that the edge will not exercise any effect if it does not cut off some of these; suppose however that it does, then the effect at P will be due to only a portion of the radiation which it would

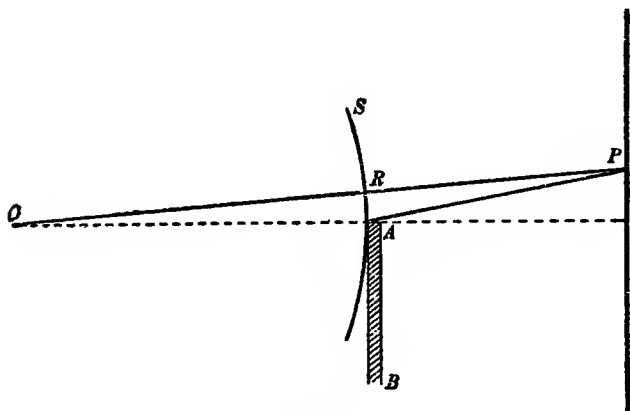


FIG. 6.

otherwise have received, and hence if AR contains an even number of half period elements $n\lambda$, the effect at P will be a minimum, if it contains an odd number $\frac{2n+1}{2}\lambda$ a maximum, an opposite condition to that considered under interference.

Diffraction of this nature has not been observed with any other supra-lacunal radiation than light, probably on account of the very small intensity of the images.

To obtain greater intensity a diffraction grating is employed ; this consists of a large number of equal and equidistant rectangular apertures of a width depending upon the radiation, thus Hertzian waves can be diffracted with a tin-foil grating, while for light, glass or metal plates are ruled with as many as 40,000 lines to the inch, the former being used for transmission and the latter for reflection.

With a trans-radiable grating with apertures of width a , and obstacles of width b , the effect at any point will depend upon whether the rays from the separate apertures interfere or not, and they will interfere if their paths differ by an odd number of half wave-lengths. If then θ is the angle of deviation $(a+b) \sin \theta = 2n \frac{1}{2} \lambda$ for maxima and $(2n+1) \frac{1}{2} \lambda$ for minima ; and since $\sin \theta$ varies as λ , rays of different frequencies receive different deviations, so that a heterogeneous radiation is drawn out

into a spectrum, which has an equal dispersion throughout, and does not depend upon the substance of the grating; it is hence very preferable to a refraction spectrum for accurate measurements.

The deviations are inversely proportional to $(a+b)$ so that dispersion will be increased by decreasing the width of the apertures and obstacles.

§ 7.—Polarization.

The term polarization is unfortunately used in science for two very dissimilar phenomena, and the particular significance which belongs to the present subject is the one to which the term is the least applicable. When a radiation is said to be polarized it is meant that for some definite time the series of changes involved in the oscillation reproduce themselves in an *exactly* similar manner at any specified place, while there is reason to believe that this is not the case with unpolarized vibrations.

These changes, which are now considered to be of an electro-magnetic nature, are supposed

to be such that the periodic variation in the electric displacement at any point can be represented in general by an ellipse, which in two special cases reduces to a straight line or to a circle, these forms being known as elliptic, plane, and circular polarization respectively. Since the vibrations we are now considering are transverse, the plane of the ellipse is at right angles to the direction of propagation of the radiation, and consequently the only variations which can take place in the ellipse are those affecting the directions and relative magnitudes of its axes.

In radiations in which a constant type of polarization obtains, both of these variations are necessarily absent. By artificial means it is possible to vary the directions and relative ratio of the axes, for it has been found that a continuous rotation of plane polarized light about an axis parallel to its direction converts it into an unpolarized beam, while if the polarization of the beam is originally elliptical it will become circular by rotation. It is thought that this is akin to the process which is occurring in natural light, and hence that

this consists of a plane polarized vibration in which the plane of polarization is constantly changing its direction.

It would be out of place here to discuss the relations between elliptical, plane, and circular polarization and the methods of producing and detecting them, so that we shall confine our attention mainly to plane polarization, calling attention to cases in which there is any marked difference from the other forms. The various means for producing a polarized beam will be first considered, and then the properties of a polarized as distinct from an unpolarized beam. When considering any particular radiation, it is immaterial whether it is assumed to be unpolarized and then to be brought into the polarized condition by some method of treatment, or whether it is first considered as polarized, and is then *depolarized* or *analysed* by the same treatment. Since the infra-lacunal waves as they are usually produced by a linear oscillator are plane polarized, they will fall under the second head, while, excepting in a few special cases, all supra-lacunal waves are naturally unpolarized. Polarization in the

above sense can be obtained with any radiation, either by transmission through, reflection from, or refraction in, a suitable medium. The infra-lacunal waves have been mostly analysed by transmission, and it was found by Hertz that a medium could be built up for the purpose, by employing parallel conducting wires, the system only transmitting the component of the electric force normal to the wires; the same results have been subsequently obtained by the use of jute fibre in place of the wire, and also with naturally fibrous substances, such as serpentine (Bose).

The reflected and refracted beams considered on page 95 are in general polarized, and always to the *same* extent; it is also found that the planes of polarization of the two beams are at *right angles* (Arago). The nature and amount of the polarization depends upon—

- i. the angle of incidence;
- ii. the nature of the substance;
- iii. the frequency of the vibration.

For any particular substance of refractive index n there is a certain angle known as the

polarizing angle i , at which the polarization attains a maximum. Brewster found that $\tan^{-1}i=n$, which shows that then the reflected and refracted portions are at right angles. Usually, however, the polarization is not complete even at this angle, and Jamin has shown that this is only the case with substances whose refractive index is 1.46.

As a rule, reflection from non-radiable substances does not give a plane polarized, but an elliptically polarized beam, this being probably due to the combination of the slight rotation of the plane of polarization which seems to be always produced on reflection, and the interference of the portions reflected *at* the surface and at some small distance *below* this (see p. 98). Some support is given to this view from the experiments of Zehnder (*Wied Ann.*, 53, p. 505, 1894), who employed two wire gratings such as are mentioned on p. 119 and p. 125; these were placed in the "crossed position" behind one another, and the front one was arranged so as to reflect a portion of the incident radiation; the other portion, after traversing the first, was reflected

almost entirely by the second grating ; on then retraversing the first, it interfered with the one simply reflected there, producing an elliptically polarized ray.

The most usual method of obtaining polarized beams is to employ those produced by double refraction. But since the presence of the two would cause confusion, it is usual to remove one of them, either by the employment of a strongly dichroic substance such as tourmaline, which removes it by absorption ; or by causing the two to fall on to a reflecting surface at an angle which is greater than the critical angle for one of them, usually the ordinary ray, which is hence totally reflected out of the way. In principle, Nicol's, the most used form, consists of two half crystals of the same substance separated by a layer of another medium (B) which should be in perfect optical contact. The indices of refraction are taken, so that for the particular rays used, n_B is greater than one index and less than another index of the crystals, hence the ray corresponding to the first will be totally reflected if the angle is properly chosen.

For electrical waves, rhombic sulphur prisms.
„ heat, etc. „ calcite „
are usually used.

Incandescent solids and liquids were found by Arago, in 1824, to emit polarized vibrations in directions which were oblique to the surface. These experiments have been extended by Mullikan (*Phys. Rev.*, 1895), who investigated non-conductors as well as solid and molten metals. It was found that at the grazing angle the light from incandescent platinum was almost completely plane polarized, and that the condition of the surface had considerable influence. The evidence points to the view that the radiation is refracted by the molecules near the surface and is so polarized. Gases and flames do not normally emit polarized vibrations but can be made to do so. The effect of a magnetic field on a substance emitting light was investigated in the first instance by Faraday, and subsequently other observers have attacked this subject, but until recently with quite negative results. The experiment does not seem to have been tried with the supralacunal waves nor with the infra-red at present.

A change of frequency was, however, predicted theoretically by Lorentz, and discovered by Zeemann (*Phil. Mag.*, March, 1897), with sodium, and it has been observed with other substances, such as lithium, cadmium, thallium, strontium. The method consists in placing the source of light between the poles of a powerful electro-magnet, arranged so that the light can be observed either along or across the lines of force with a spectroscope giving a good definition and dispersion.

On making and breaking the current the line is seen to widen out and to narrow respectively, and further investigation shows that—

I. Along the lines of force the line tends to split into *two, both completely circularly polarised in opposite directions.*

II. Across the lines of force the line tends to split into *three*, of which the *two outer* are *vertically* and the *middle horizontally* polarised.

The analytical investigation of Lorentz shows that the widening T' is proportional to the square of the frequency T and to e/m a quantity further considered on page 203.

Reflection and
Refraction of
Polarized
Vibrations.

The general discussion of the reflection of polarized beams includes all possible relations between the planes of polarization and incidence, which may vary between the two extreme cases of being parallel or normal to one another, but these limiting cases will be the only ones considered here.

As stated above (p. 56), electro-magnetic vibrations have been found to have the electric force normal to, and the magnetic force in, the plane of polarization ; hence, in the first case mentioned above the electric force is *normal* to the plane of incidence, and the theory shows that the ratio between the reflected and refracted portions should increase with the angle of incidence. In the latter case, where the electric force is *in* the plane of incidence, as the angle of incidence is increased the ratio between the reflected and refracted portions *decreases* to the polarizing angle for the substance (*see* p. 120), and then increases to grazing incidence (*cf.* p. 124).

A. D. Cole (*Wied Ann.*, 57, p. 290) has experimentally verified these results of the

theory for the infra-lacunal waves, since he found that—

	Case I.	Case II.
1 mm, zinc at an incidence of 45°		
reflected	100%	92%
1 mm. water, ditto	71.8%	52.7%

And Hertz demonstrated the same, but less accurately, from the surface of a brick wall.

It is with these vibrations, on account of their size, that the reflecting surface can be built up of a definite structure; thus a wire grating with the distance between the wires depending on the wave-length of the oscillation, but being in general about $1/100$ of this, will reflect the whole of the component that is at the right angles to the wires, and will transmit the remainder (*see* p. 120) for normal incidence, while at oblique incidence it obeys the above laws.

Fresnel and MacCullagh advanced theories of the reflection of polarized light which had some points of difference. It is now seen, however, that they were merely treating two portions of the same phenomenon; for in Fresnel's theory the displacement is normal to the plane of polarization, and hence he was considering the

electric force, while MacCullagh was treating the displacement in this plane, which is the magnetic force.

It is found that there is a slight rotation of the plane of polarization on reflection from dielectrics (*see Rotation*, p. 128).

Absorption. Few experiments have been made

as to the relation of the plane of polarization to the radiability of substances for the Hertzian waves, although any polarizing substance, such as serpentine, would probably exhibit such a difference, and from the reflection phenomena quite regular results would be expected.

Certain substances have been found to show marked dichroism with the infra-red rays, such are calcite and tourmaline (Merritt, *Phys. Rev.*, 2, p. 424). In these crystals the coefficients of absorption of the ordinary and extraordinary rays were quite independent, and an examination of the spectra with a bolometer allowed the bands to be mapped; it was found that between $\lambda = 23000 \times 10^{10}$ and $\lambda = 34800 \times 10^{10}$ the curves crossed so that the dichroism became reversed and remained so to $\lambda = 55000 + 10^{10}$.

It seems probable that all doubly refracting substances would be dichroic for vibrations of some frequency, and all fresh experiments seem to confirm the supposition.

With light waves many substances were shown to be pleochroic, by Brewster (*Phil. Trans.*, 1819), and some are sufficiently so, to show a change of colour when viewed from two positions at right angles in sunlight owing to the slight amount of polarization which usually occurs in this ; good specimens of glauconite giving a fine blue shade in one direction and a dull brown in the other. With transmitted light, hornblend, biotite, and tourmaline are perhaps the most striking.

The maximum colour effect in any case is clearly attained when the light so traverses the crystal as to be normal to the axes of greatest and least elasticity. This property is one of the most useful in the determination of crystals, for uniaxial crystals are dichroic and biaxial are trichroic, while the colour changes are very often peculiar to the particular mineral.

Interference. To produce interference the two rays must have originally belonged to the same ray as with unpolarized radiations.

If two plates of a doubly refracting substance are introduced into the paths of two such rays, in general four rays will be produced which will interfere in pairs. When the principal sections of the plates are parallel the two ordinary rays will interfere and also the two extraordinary. When the principal sections are at right angles the ordinary ray from each will interfere with the extraordinary ray of the other, and the fringes will be displaced owing to the different velocities of these rays.

Where the ordinary ray is removed, as with tourmaline or a Nicol's prism, the fringes entirely disappear when the principal planes of the plates are at right angles.

Rotation of the Plane of Polarization. This phenomenon can be produced in various ways which may ultimately be found to be due to the same cause, although at present there seems little connection in some cases.

The various methods may be grouped as follows :—

- | | | |
|--|---|--|
| <i>Transmission</i>
<i>through.</i> | { | 1. Certain crystalline substances. |
| | | 2. Certain carbon compounds
(liquid or in solution). |
| | | 3. Substances in a state of strain.
<i>a</i> magnetic or electrostatic.
<i>b</i> mechanical. |
| | | 4. Thin metallic sheets. |
| <i>Reflection</i>
<i>from.</i> | { | 5. Dielectrics. |
| | | 6. Magnetic substances. |

Of these 1 and 2 differ from the rest in that the sign of the rotation in these cases always has the same relation to the direction of the radiation, while in cases 3-6 the rotation is independent of this, and continued retransmission or reflection merely increases the amount of the rotation.

In all the cases 1 to 4 the amount of rotation depends upon the thickness of substance traversed and the frequency of the radiations, and it is probably for the latter reason that no cases seem to be known in the case of infralacunal waves.

Until recently it was only assumed that the

plane polarized radiation was split up on entering the substance into two opposite circular ones, which were retarded to different extents during their passage so that on their recombination a plain polarized beam of a different azimuth would be obtained. This view has, however, received some confirmation from the experiments of Cotton and Cornu (*C. R.*, 122), who found that the double tartrate of potash and ammonium absorbs as well as retards the beams differently, so that an elliptically instead of a plane polarized beam results on their recombination.

1. Certain biaxial crystals show a very marked rotation when the radiation traverses them in a direction which is parallel to one of the optic axis, of these quartz is the most common, and it is found in right and left handed varieties which differ slightly in crystalline form.

2. All the substances of known construction which cause rotation when liquid possess at least one asymmetric carbon atom, that is one which is combined with four different groups. It is not sufficient that the molecular weights

of the groups be different, they must actually be constructed in different ways, and when there is more than one asymmetric atom, the groups must be so combined that the molecule as a whole has no symmetry.

3. The optical rotating power of isotropic substances of high refractivity when under the influence of a powerful magnetic force was first observed by Faraday (*Phil. Trans.*, 1846), and is hence known as the Faraday effect. In his experiment he employed a block of heavy glass (siliocoborate of lead) placed between the pierced poles of an electromagnet, for the effect is a maximum when the direction of the light is the same as that of the lines of force; and is called positive when it is in the same direction as the hands of a watch between the poles and *facing* the N pole. It has been observed in many solids, in liquids (Faraday, *loc. cit.*; Townsend, *Phil. Trans.*, 1896), and in gases (Becquerel); the amount of the rotation being equal to "Verdet's constant" depending upon the substance $\times$ the difference of potential. This constant has been found to be

+ *ve* for Most isotropic substances.

Thin sheets of iron, nickel, cobalt.

Oxygen gas.

– *ve* for Solutions of ferric chloride,

With heat waves de la Povostayne demonstrated the phenomenon, but obtained small rotations, though Tyndal, using Faraday's apparatus, but commencing with a permanent deflection of the galvanometer, was able to show the effect in a thoroughly satisfactory manner.

The experiment seems to have been tried with infralacunal waves by Bose (*Phil. Mag.*, 43, p. 57), but he has not yet published his results.

The effect of electrostatic stress was discovered by Kerr (*Phil. Mag.*, 1895), and was found to be greatest when the plane of polarization was inclined at an angle of 45° to the lines of force.

It was thought by Villari that rotating the substance at a speed of 200 revolutions per second prevented the optical change, but Duperray (*J. de Phys.*, 5, p. 540) found that this was a spurious effect due to the strain

produced by rotation, since mechanical strain on such a substance as glass is able to put it into a uniaxial condition.

In cases 5 and 6 it is probable that the rotation produced on a reflected radiation is due to the retardation of one of the components, possibly by the phase change mentioned on page 99; this is more simply shown by dielectrics than non-radiable substances, for there is no second portion to produce elliptical polarization as with metals.

Magnetic substances show the phenomena to a very large extent, and the twist produced in the small distance to which the radiation can penetrate shows what an enormous rotation must obtain in such substances, the observed rotation being in the same direction as that of the supposed magnetic vortices.

It is found with plane polarized light that the maximum effects are

Leakage of
Electric
Charge.

obtained when the plane of polarization of the incident vibration is normal to the plane of incidence, which brings the electrical oscillation into the plane of incidence. When this is the case the maximum is obtained at an

angle of about 60° , the effect being distinctly less at normal incidence (Elster and Geitel, *Phil. Mag.*, 41, p. 225). Conversely, when the electric displacement is normal to the plane of incidence, that is, has no component normal at right angles to the plane of the exposed surface, the effect is practically zero at normal incidence, but shows small values for other angles (*Electrician*, 35, p. 272, 1895).

Experiments with ultraviolet rays, to which most substances are sensitive, are very difficult to carry out, but the use of potassium sodium alloy avoids the difficulty as it is sensitive to the visual rays.

§ 9.—Influence on the Distribution of Electricity.

The electrical condition of substances is found to be subject to many variations when exposed to these radiations, and certain of the latter produce more marked effects than others.

An examination of the various possible factors shows that the phenomenon depends upon the following—

1. The frequency of the radiation.

2. The chemical and physical condition of the substance.
3. The electrical condition of the same.
4. The nature of the surrounding medium.

The Frequency. The infralacunal waves have little influence upon a charged and insulated substance, but when they fall upon the surface of a conductor, an alternating current is produced in this which is found to be confined almost entirely to the surface layer when the frequency is that of the Hertzian radiations, for Hertz demonstrated that an insulating rod covered with gold leaf was as good a conductor for these radiations as a solid metal one; the more rapid waves of this type exhibiting the phenomenon in a still more marked manner.

The longer supralacunal vibrations do not appear to have any direct effect of this description, but by their heating power they may alter the resistance of a conductor which is conveying a current, thus causing an alteration in this current; or they may, by heating a thermo-electric junction, produce a flow of electricity round the circuit. Applications of these two cases are considered under § 3.

The immediate infra-red and luminous vibrations possess other properties, for when these rays fall upon certain substances with an initial charge, this is found to alter, and many substances with no initial charge are found to acquire one. With ultraviolet radiations the loss or acquirement of a charge, or the production of a difference of potential between charged and uncharged portions of the same substance is, as a rule, more marked than with the slower vibrations, but this is not always the case. There seems a large amount of evidence to show that the loss of charge in particular is due rather to a change in the surrounding medium than in the charged substance.

**The Charged
Substance.**

Although the loss of charge exhibited by certain charged and insulated metals, when acted upon by the more rapid supralacunal waves, probably finds its cause in a change in the dielectric, yet the metals exhibit great differences among themselves. The following table shows the least rapid rays which can affect the particular metals given, all more rapid rays having, as a rule, greater effect ; for while

Potassium	}	are sensitive to the infra-red rays (Elster and Geitel, <i>Wied. Ann.</i> , 52, p. 453),
Sodium		
Rubidium		
Zinc	}	are affected by light,
Aluminium		
Magnesium		
Copper	}	by the ultraviolet,
Silver		
Gold		
Mercury	}	by the extreme ultraviolet ;
Platinum		

for the infra-red rubidium is more sensitive than potassium, but the order is reversed for light ; while sodium is more affected by green rays, and potassium by the blue. The following numbers show the relative sensitiveness of these metals to four types of rays, the values having been all made to correspond for white light—

	White.		Blue.		Yellow.		Orange.		Red.
Rubidium	1	...	16	...	64	...	33	...	39
Potassium	1	...	57	...	07	...	04	...	002
Sodium	1	...	37	...	36	...	14	...	009

The alkali metals are rendered even more

sensitive when surrounded by an electro-negative gas, such as oxygen or carbon-dioxide.

Many fluorescent and phosphorescent substances exhibit the phenomenon well, some to an extent which rivals zinc, and these substances are always extremely powerful absorbers of radiations which differ little in frequency from those which produce the maximum discharging effect on them.

The Sign of the Charge. Many observers (Hallmachs, Righi, etc.) agree in finding that negative charges are lost far more rapidly than positive, at any rate, with bright, clean surfaces ; but Lodge (*Science Progress*, vol. iii. p. 175) finds that a *dull* surface loses a positive charge more rapidly than a negative, and Elster and Geitel (*loc. cit.*) remark that this is the case with cobalt under all conditions. The metals at the bottom of the above series not only lose their negative charge more slowly than the others, but also acquire a positive charge with greater facility. To explain these effects, we may consider that the absorption of the radiation has produced a great increase of kinetic energy in the surface layer, which might allow

more charged atoms than usual to get beyond the layer, and as it seems that usually the charge tends towards a positive value, we must assume that the negatively-charged atoms are able to become free more easily than the positive.

At ordinary pressures, at which the
**The
Surrounding
Medium.** experiments were tried, Wiedemann and Ebert have found that carbon-dioxide permitted a greater rate of leakage than any other gas with which they experimented, and it is probable that the same relationship would be found in this case as exists for the Röntgen rays (see p. 252).

The pressure of the gas has a very great influence on the rate of leakage, on the potential required to produce a spark between metallic terminals, and also upon the influence of a magnetic field upon the former; for with the magnetic force acting parallel to the surface (the direction which produces the maximum effect), while there was no effect at normal pressures, at '002 mm., the rate of leak was reduced by one half: that is, the magnetic field tends to prevent any change which may be occurring.

The influence of the more rapid ultraviolet rays upon the spark length, or what comes to the same thing, the initial potential required to produce a spark, was first observed by Hertz with the radiation from another spark, and Wiedemann showed that the rays from the negative terminal were the most efficient. It is well known that under ordinary conditions the difference of potential at the terminals required for the first spark is many times, and with dry gases as much as seven times that required subsequently. Warburg has found (*Sitz. Berlin*, 12, p. 223) that the effect of the radiation is to abolish this difference, and that, if any change is produced on the steady difference of potential, it is in the contrary direction. The loss of charge of illuminated substances and the reduction in the initial potential required for a spark to pass between illuminated terminals, point either to the existence of a species of electrolytic conductivity in the gas, or to charged particles of metal which convey away the charge by a process of convection. To decide between these views it is necessary to examine the

properties of the gas under the influence of the radiation in order to find whether it does suffer a change. An obvious investigation is concerned with the relation between the pressure of the gas and the E.M.F. required. In one conducted by Stolitoﬀ the radiation passed between two plates connected to the terminals of a battery, the current flowing in the circuit being observed when the gas was at different pressures. It was found that a critical pressure, at which the current was a maximum, existed for each difference of potentials employed, and that this decreased with an increase in the E.M.F., while Righi states that the critical pressure is the same for this steady current as for sparking. The relation of current to E.M.F. in Stolitoﬀ's results show that, although the former tended towards a maximum, yet the saturation current was not quite reached, though such a state has been produced with the Röntgen rays (p. 259).

Photo-Electric Cells. As early as 1839 E. Becquerel showed that when two sheets of the same substance (AgCl) were immersed in a liquid, and one of them was exposed to light

that a difference of potential was produced between them. Although most substances can thus be made to acquire a difference of potential, it was soon observed that the effect was far greater with some than with others, and Minchin (*Phil. Mag.*, vol. 31, p. 223) has found that the sign of the exposed plate is not always the same. Thus, while with silver plates, with a coating of chloride bromide or sulphide,¹ the potential of the exposed plate is negative, when the surface is the iodide it is positive. Tin in methyl alcohol showed the exposed plate as positive; but aluminium, with a coating of selenoaluminium in acetone, as negative. The latter gave by far the best results, and was prepared by melting some selenium on to an aluminium plate.

Rigollot has continued the study of different substances (*J. de Phys.*, October, 1897), especially with reference to the radiation which gives the maximum effect. He found that in all cases there was a small initial difference of potential between the unprepared and prepared plates, these latter being "prepared" by a

¹ Rigollot, *C.R.*, 121, p. 164.

coating of chloride or other salt, and that the radiation always increased this difference. It was proved not to be due to thermal causes, for a rise in temperature diminished the sensitiveness.

Better results were obtained with plates which had been dipped into a solution of one of those dyes which are used in the preparation of ortho-chromatic photographic plates, such as eosin, methyl violet, etc. ; for instance, a pair of plates which normally gave an E.M.F. varying between 5×10^{-5} and 200×10^{-5} volts, when sensitised with malachite green, gave an E.M.F. of 300×10^{-5} volts.

In each case the substance in question was observed by gradually allowing a spectrum to pass over it and noting when the maximum E.M.F. was obtained ; the sensitising dye was also examined and its principal absorption bands noted ; in all cases it was found that the radiation which gave the maximum effect was one of a frequency somewhat *less* than that of the principal absorption band.

The following table is quoted from the paper referred to as it shows very well how the maxi-

num position changes with the sensitising substance, the numbers being the wave-length which gave this.

λ in $\mu = 10^{-7}m.$		<i>Sensitised with</i>
1'04	Silver Sulphide	
'660	Tin Sulphide	
'657	Copper „	Malachite Green
'622		Methyl Violet
'620		Cyanin
'614		Formyl Violet
'588		Soluble Blue
'570	Copper Bromide	
'560	„ „	Safranin
'554		Eosin
'540	Copper Chloride	
'572	„ Oxide	
'464	Sulphide	
'460	Tin Oxide	
'410	Copper Iodide	
Ultraviolet	„ Fluoride	

It has been stated above, p. 135, that certain radiations increase the resistance of conductors owing to their heating powers, but the converse effect is also known, for selenium when under the influence of light shows a *decrease* of electrical resistance which often amounts to one-half, within limits the change of resistance varying as the square of the illumination. It

is found that the best results are obtained with selenium which is of a greenish yellow colour and is crystalline, and Bidwell (*Phil. Mag.*, Aug., 1885) agrees with Adams and Day (*Phil. Trans.*, 1887), who state that the conductivity is of an electrolytic nature, being due to the presence of selenides which have been formed by the combination of the selenium with the material of the vessel in which it was melted, for when they carefully prepared selenium without contact with metal, its resistance was initially very high and remained so under the influence of the radiation.

As with the photo-electric cells, the effect of heat is contrary to that of the radiation, so that the two effects cannot be mistaken for selenium. With sulphur, however, which is also sensitive when melted on to a silver surface, the effects of radiation and of rise of temperature are both to decrease the resistance.

§ 10.—Chemical Effects.

These effects are the result of the absorption of those radiations which can directly influence the vibration frequencies of the mole-

cules and atoms, and as the latter are undoubtedly very rapid we should expect to find the more rapid radiations having the greater effect; and also that without very special arrangements no effect would be produced at all by any radiations with frequencies differing much from these. Such is not quite the case, for de Hempstinne (*Zeit. Phys. Chem.*, 1897, p. 358), has found that Hertzian waves decompose 95% of ammonia, cause a 4% combination of N_2 and H_2 and also decompose CS_2 . But the infra-red rays probably owe their influence to their heating power.

Abney (Bakerian Lecture, *Phil. Trans.*, 1880) has, however, obtained emulsions of silver bromide which are directly sensitive to radiations with a wave length of nearly three times that of the A line and a frequency of about 10^{14} per sec. To attain this end the silver bromide was so produced that the molecular aggregates are much larger than usual, and the film is further prepared by the addition of dyes which absorb the infra-red rays and which usually colour it a bluish green; potassium iodide brought the spectrum to

$\lambda = 10,000 \times 10^{-10}m$ and a certain blue dye in carbon tetrachloride down to $13,000 \times 10^{-10}m$.

The visual rays affect specially prepared photographic emulsions over the entire spectrum, and they also induce other chemical reactions. A mixture of chlorine and hydrogen gases was shown by Pringsheim (*Wied. Ann.*, 32, p. 394) to be sensitive to them, and Wild and Harker (*Electrician*, 38, p. 690) state that it is more sensitive to these rays than to the ultraviolet. Their experiments show that combination does not occur immediately on exposure although contraction does, so that after a succession of instantaneous exposures separated by intervals of more than 30 seconds no hydrogen chloride could be found. It is probable that these effects are due to the appreciable time which the radiation takes to decompose the gas, as a preliminary to its recombination.

Ultraviolet radiation is able to produce nuclei for cloud condensation in moist air, as shown by Wilson (*Proc. Camb. Phil. Soc.*, Jan., 1898), and he suggests that the blue of the sky may be due to the nuclei produced by

the more powerful ultraviolet radiation in the upper regions of the atmosphere. It is probably due to ionization (cf. page 256).

Draper was the first to point out that the plant cell had the greatest capacity for the production of cellulose and oxygen from water and carbon dioxide when under the influence of the green and yellow rays, possibly because of the great absorbent power of chlorophyll for these rays.

Besides silver salts, many other substances show photo-sensitiveness when in the presence of some colloidal carbon compound such as gelatine or collodion, the most used practically being potassium ferrocyanide, potassium bichromate, and platinum chloride. In most cases the effect is not visible to the eye, and the latent image has to be developed out by the use of suitable reducing agents, with or without the addition of more of the metallic salt employed.

The ultraviolet rays have a more energetic action on the majority of these compounds than any of the less rapid vibrations, and hence photographs of natural subjects rarely give the

true effects of chiaroscuro as they would be shown in an accurate black and white reproduction of the same. The use of emulsions which are sensitive to all colours to a nearly equal extent, combined with the judicious use of coloured screens, is making better results obtainable.

Much has been heard recently about photography in natural colours, mostly from France, but the results obtained are not very satisfactory, and Lippmann's process is, up to the present, the most satisfactory method of which an account has been published. It depends upon the use of a mercury surface on which the film is laid, and which reflects the normally incident light so that stationary wave forms are produced; hence a series of extremely thin layers of reduced silver are formed at equal distances throughout the film, the distance between any two layers at any point depending on the wave length of the light there. These layers cause the film to show the various colours when viewed by transmitted light.

Abney has experimented on the difference between the effects produced by a continuous

exposure and a series of intermittent ones of the same total duration for photographic emulsions; he finds that the latter case always produces a less effect, and that the longer the interval *between* the exposures, the smaller was the effect produced (cf. p. 147).

Many other interesting phenomena, such as periodicity of the chemical action, are known; this is shown by giving a film an exposure enormously greater than the normal, when it will for certain times return to a sensitive condition, although not quite to its initial one.

§ II.—Physiological Effects.

The difference between the phenomena produced by radiations of various wave lengths is more marked with these than perhaps with any other effects that they can produce, and to this is largely due the artificial division of the electro-magnetic radiation which used to obtain.

Hertzian radiations, even when of great intensity and of the shortest obtainable frequency, appear to be completely unable to affect living bodies and this is the more remarkable as the "cold rays" have been shown by Pictet

(*C. R.*, Jan., 1895) to possess a most marked and beneficial effect on human beings.

The ordinary infra-red radiations, since they possess the power of causing a rise in temperature in all substances which they penetrate, have, as is well known, a marked effect due to this property, which is also shared by the luminous radiations to a smaller extent if their amplitude only is considered, though Langley has shown that the greatest heating effect occurs in the green of the solar spectrum as we obtain it. If we were not endowed with a particular organ for observing the octave of radiations we call light, we should only be able to detect them by their heating effect, when they would show little diversity from the immediate infra-red rays.

This is not so with the ultraviolet radiations, for these are found to have a special and curious effect upon the skin of the higher animals and on the entire tissues of the lower, as well as on those of many plants, which latter appear to be also sensitive to slower vibrations.

The darkening of the skin in men who in-

habit tropical regions, and the incipient action which shows itself in freckles and sunburn, together with the formation of the green colouring matter of plants, is undoubtedly due to the specific action of waves having a frequency not differing much from that of violet light. The cause of sunburn has been carefully investigated (*Alpine Journal*, 1888) and is shown to be most excessive when the air is very clear and there is a brilliant reflecting surface such as snow, while painting the skin brown was found to almost prevent the action. Similar observations were made by Tyndal with the arc light.

PART III

OTHER FORMS OF RADIATION

THE radiations included in this part are best considered separately from one another; not so much, perhaps, on account of any intrinsic difference in some cases, but because in the present state of our knowledge, the connection between them, if visible at all, is usually obscure, and hence a general method of treatment would only tend to confuse the subject.

As will be seen in the chapters devoted to them, the radiations of Becquerel and Le Bon are probably really electromagnetic, but they have not been included in Part II. because their position in the ethereal gamut cannot yet be definitely settled.

CHAPTER I

THE PHENOMENA CONNECTED WITH THE VACUUM TUBE

BEFORE discussing the radiations themselves, we will briefly consider the phenomena connected with the discharge of electricity through gases, under other conditions than those necessary to produce the cathode and Röntgen radiations, and the influence which variations in the difference of potential at the electrodes, and the nature and pressure of the gas, have upon the discharge.

The discharge is the result of a breaking down of the dielectric under an intense electrostatic field of force, the gas being conveniently contained within metallic or glass tubes, so that the pressure can be varied. The necessary difference of potential is obtained either by conveying a current round the outside of

the tube (the electrodeless discharge), or by sending a current through the tube by the aid of metallic electrodes. The only discharges that will be considered are those which are produced by an intermittent current which is equivalent to a series of impulses.

Such a current can be obtained
The Current. from an induction machine like the Wimshurst, or by a mechanical arrangement which allows a battery of condensers to be charged in parallel and discharged in series many times a second. It is more usually obtained by using either an alternating current or a steady one connected to an induction coil. An alternating current can be obtained direct from a dynamo, but the frequency is too low, and has to be increased by the aid of a Tesla transformer. This apparatus is sometimes preferable to the more usual induction coil.

The advantages of the Tesla apparatus are that it is cheaper and more simple than a coil, and is not damaged by the passage of an excessive current. The intensity of the secondary current is practically constant, and is thoroughly under control, so that more uniform working

conditions can be obtained ; finally, if the whole installation has to be considerably increased, it can be done at much less expense.

The principal objections are the necessity of using special tubes (p. 209), and the noise caused by the passage of the sparks across the gap ; but this could possibly be remedied by some simple mechanical contrivance.

The most generally used method is the one employing an induction coil and some source of electricity giving a *steady* current as opposed to the alternating current required for the Tesla. For most purposes a coil giving a four-inch spark is sufficient, and it is little use increasing the size of the coil unless special tubes are also employed. Apart from any question of efficiency or of damaging the tube, it is quite obvious that it is useless to employ a current and coil giving a spark of greater length than the distance between the outside terminals of the tube electrodes. On account of the long periods for which the coil may have to be kept working, it is important to see that the contact breaker is of a suitable character. Very large coils are generally made with a mercury inter-

rupter quite independent of the coil itself, but, though of high efficiency, this is not altogether convenient for coils of more moderate dimensions, to which a hammer break is usually fitted. It is in the construction of these breaks that many coils are ill adapted for the class of work now under consideration, as the discs of platinum at the end of the screw and at the back of the hammer are made too thin and not sufficiently well fixed to their respective supports, so that they are liable to become overheated and to drop off. When portability is a desideratum, the accumulator and coil is certainly to be preferred to all other forms of apparatus, and it has a further slight advantage in the way of quietness over the Wimshurst or Tesla. In using a coil it has been found that the best results are obtained when the axes of the tube and the coil are parallel to one another.

Electrodeless discharge. Since the effects in the tube have been found to depend very largely upon the character and shape of the electrodes, it is simpler to first consider the phenomena when no electrodes are used. To produce an electrodeless discharge, a bulb is brought to the

right state of exhaustion, and is surrounded by a coil of wire conveying the current. When the current and the exhaustion are suitable, an annular discharge is seen in the bulb, with the axis of the ring in the same direction as that of the coil of wire.

The luminosity of this discharge varies with the conditions, but seems to arrive at a maximum at pressures less than $\frac{1}{200}$ mm., and by analogy with the discharges at such pressures in tubes with electrodes, it might be expected that other radiations besides light would be emitted. Such rays have been sought for, but have not been usually detected, though on page 171 a special case is mentioned where cathode rays are produced in this manner.

One of the most striking features of the electrodeless discharge is the enormous conductivity which gases exhibit under these conditions in comparison with that shown by electrolytes, or by the same gases when electrodes are used. The behaviour of the discharge in the presence of metal plates throws some light upon this difference, for J. J. Thomson¹ has shown that a

¹ *Recent Researches in Electricity and Magnetism*, p. 98.

metal diaphragm in the tube completely divides the discharge, and that two or three prevent its occurrence. The marked objection which the discharge shows to passing from one substance to another is connected with the cathode fall of potential, the spluttering of electrodes, and the absence of lines of the metal in the spectrum, emitted by a gas containing metallic dust in suspension (Liveing and Dewar, *Proc. R. S.*, 48, p. 437, 1890).

The effect of a magnetic field on this discharge is to twist it into a spiral whose axis follows the direction of the lines of force.

With Electrodes. The presence of electrodes largely alters the nature of the discharge which, according as the conditions are varied, can have all gradations between the disruptive spark produced by a high difference of potential in gases at the atmospheric pressure, and the glow discharge observed in high vacua.

Spark Length and Potential difference. When the spark length is considerable, the relation between the potential difference v . required and the spark length l is simple, and according to Foster and Pryson (*C. R.*, 1884, p. 44) is expressed by the

relation $v. = a + \beta v$, where a and β are constants depending upon the nature and pressure of the gas, etc. For distances of less than a millimetre the potential difference is higher than that given by this relation, and consequently there is a minimum value which is found to be almost independent of pressure, and which is found not to differ much from 300 volts. It is hence much greater than the minimum value for the electrolysis of liquids, but is approximately equal to the cathode fall of potential. The distance at which this potential difference will produce a spark is dependent upon the nature and shape of the electrodes, and the nature and pressure of the gas.

Electrodes. The material of which the electrodes are composed is usually metallic, though carbon has been used, but this rapidly disintegrates, as also do certain metals, which "spluttering," as it is called, tends to alter the conditions in the tube at low pressures. In spite of the difference which metals show in this respect, Righi (*N. Cim.*, 1896, p. 97) considers that they do not differ in the potential difference required to produce a spark under given

conditions. This conclusion is not confirmed by others, who consider that aluminium requires a less potential difference, for J. J. Thomson (*Phil. Mag.*, Oct., 97) finds that in the same tube iron terminals require the use of much higher potentials than aluminium.

The shape of the electrodes has considerable influence on the ease with which a spark will pass from them into a gas, and it is found that a spark will occur more readily between points than between small spheres, and with these more easily than between plates, a result which is of common experience when the ease with which the brush discharge takes place from points is considered.

Investigations concerned with the
The Gas. relation between the nature of the gas and the sparking distance differ so much in the results obtained that no general conclusions can be drawn, though most observers agree in giving carbon dioxide a greater dielectric strength than air for short sparks and a less strength for long. The spark lengths for a large series of gases have been measured (*Wied. Ann.*, 1889), showing that in general

this varies inversely as the complexity, except with the hydrocarbons, and in much the same way as the dielectric constants of the same gases.

When the pressure is constant the spark length is also inversely proportional to the temperature, which may be considered as merely effecting an alteration of density. The relations between the pressure and the spark length and also the other phenomena which replace the spark at low pressures, are those which more nearly concern the present subject.

With a gas at about atmospheric pressure, it is found that as this is diminished the potential required to produce a given spark diminishes also, until a certain critical pressure is reached, the value of which is found to vary with the gas and the spark length. Below this pressure the required potential difference increases with the fall in the pressure. This was shown very well by Peace for pressures just about this critical one, and his results also exhibit the existence of the critical distance mentioned above.

An examination of the properties of the dis-

charge through a gas as the pressure is diminished shows that such important changes occur, that a somewhat detailed statement is requisite. Suppose a vacuum tube furnished with two electrodes which are connected to an intermittent current of high frequency such as that furnished by an induction coil suitably excited, the tube is filled with air at the atmospheric pressure and is connected to a pump for producing high vacua, and the distance between the terminals in the tube is much greater than the critical distance for such exhaustions.

For pressures greater than 75 mm. the discharge is linear; behaving like an elastic string between the electrodes, when disturbed by a transverse force such as that produced by a current of air, which repels, or a magnetic field which attracts it.

From this down to about 1 mm. the discharge still remains homogeneous and linear; but a magnetic field draws it away from the electrode, causing it to strike the glass where it produces a phosphorescent patch. At pressures of about .01 mm. the discharge becomes stratified, and the phenomena at the two electrodes become mark-

edly different. Until the striations quite disappear a certain number of these phenomena are of constant occurrence, and their appearance assists in the determination of the different stages at lower pressures. The phenomena to be observed, as shown in fig. 7, are as follows:—

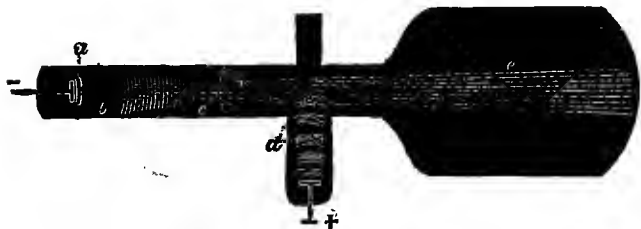


FIG. 7.

(a) Is the luminous glow round the cathode, which is of a yellowish colour, and is sharply separated from

(b) The 1st (Crookes) dark space, which is now known to be of a deep blue colour, and is, according to Crookes, the region where there is no collision between the negatively electrified particles shot out from the cathode.

(c) The Faraday space.

(d) The positive column, which is composed of a series of alternately bright and dark portions (striæ), with their convex sides away from the anode, from which they appear to proceed. They are not, however, connected to this, but to the cathode, since the anode may be moved forward without disturbing them, it merely cutting out those striæ which it passes. The discharge between the electrodes certainly takes place by means of the positive column, and a measurement of its velocity in a tube of 5 mm. diameter and at a pressure of $\frac{1}{2}$ mm. of mercury by J. J. Thomson (*Phil. Mag.*, Oct. 94), gave it about about one-half the velocity of light. In spite of this high velocity, the discharge does not seem to be continuous, for each stria acts as a separate discharge when under the influence of a magnetic field (Spottiswoode and Moulton, *Phil. Trans.*, 1889, p. 205), each being bent down in the same manner as the whole discharge for higher pressures.

The distance between the striæ depends upon the pressure, and is found to vary by a little more than the reciprocal of the density.

The whole discharge, but especially the positive column, is found to exercise a screening effect for other tubes (Wiedemann and Schmidt, *Wied. Ann.*, 11, 1897).

At high exhaustions the negative glow tends to leave the edges of the cathode and collect towards the centre, it is of a yellow colour, showing the spectrum of nitrogen, and when the cathode is perforated the glow forms rays which stream *back* from every aperture, as observed by Goldstein (*L'Éclair Elec.*, 1897, p. 364), and named by him "Canal rays." These rays are convergent, the outer rays being more bent than the inner, and their intensity seems to depend upon the area of the projection of one side of the orifice upon the other. The smaller the apertures the lower the potential which will produce them in a pure condition. The rays form shadows but do not interfere or become deflected by a magnetic field. By employing two wire gauze cathodes, Wiedemann and Schmidt (*Wied. Ann.*, 11, 1897) were able to obtain them in a more satisfactory manner in the intervening space. The rays were found to act as a screen to other

sensitive tubes and to reduce the discharge potential in the part of the tube that they traversed.

If the process of conduction of the current through the gas resembles electrolytic conduction closely, as is now supposed, we may consider that the striæ are bundles of Grotthus' chains ; this might account for the high velocity of the discharge in spite of the discontinuity of the medium, and it would seem that the current not only causes polarization among the molecules as a whole, but also decomposes individuals.

The last phenomena which we have to consider is the discharge from the cathode, which in fig. 7 is shown by a series of lines (*e*) radiating from this ; these are the *radiant electrode matter or negative rays* of Crookes.

CHAPTER II

THE NEGATIVE AND CATHODE RAYS

The Negative Rays. THE rays to which this name was given by Crookes, appear to be emitted in straight lines from the surface of the cathode, whatever its shape may be, and not to follow the direction of the lines of force, as they might be expected to do; for when a straight wire is used as a cathode the lines of force are hyperbolas with their foci at the extremity of the wire, which gives some portions a large curvature near the cathode, while the rays are emitted everywhere at right angles to the surface.

When the negative rays strike against any obstacle which is free to move, the latter tends to move away from the cathode, as it would if struck by particles emitted from this; whatever the obstacle is made of it is entirely non-radiable, even in the thinnest obtainable

layers, for not even collodion (Goldstein) or quartz (Crookes) will transmit these rays.

So far the radiations that have been mentioned are those which occur in the vacuum tube at moderate exhaustions, and we shall now consider those which are produced at higher exhaustions, and which can be observed outside the tube in which they are produced.

It is to Hertz and Lenard that we owe the first advances in the study of the rays under these conditions, and their results seem to indicate that although these rays differ in some of their properties from those considered above, they probably only represent varieties of the same phenomenon which differ from one another like the different electro-magnetic or X rays.

To avoid ambiguity, however, the term *negative rays* has been used to indicate the particular variety first observed by Crookes, and which has been more particularly considered above, while the term *cathode rays*

Cathode
Rays.

will, in conformance with the accepted usage, be employed to denote those varieties which have been investigated

of more recent years. It is, however, only a very general name, for, as will be seen, some varieties are still included in it which differ markedly from the others in certain of their properties. Lenard's researches are of such importance that considerable attention must be given to them, as they really form the foundation of the subject, but his results do not always agree well with those of subsequent observers, probably because his methods are not exactly followed.

§ 1. Production.

From what has been given on page 163 it will be seen that the production of the cathode rays in a vacuum tube depends largely upon the pressure, and it is found that their character changes somewhat as the pressure is reduced, until a point is reached at which they are no longer emitted.

Inside terminals are found to be not essential to their production, for any substance brought near the positive end seems to create a cathodic centre of emission on the glass nearest to it, and similar quasi-cathodes, ac-

accompanied by the whole series of phenomena mentioned above, are formed by any constriction of the tube. In a tube consisting of two bulbs connected by a capillary, and without any internal electrodes, J. de Kowalski (*C. R.*, 120, p. 82, 1895) found that *both* ends of the capillary emitted cathode rays.

In all experiments with cathode rays produced in glass tubes it is almost impossible to obtain any outside the tube, but if a window of a more penetrable substance, such as aluminium, is employed the rays can then be studied outside under conditions quite independent of the changes taking place within the tube. To Lenard (*Wied. Ann.*, 51, p. 225, 1894) is due a very complete investigation of certain properties of the rays, produced in the following manner, fig. 8 showing the apparatus ultimately adopted by him.

The cathode, *K*, is an aluminium disc connected with the outside of the tube, and ultimately with one terminal of an induction coil by a long wire passing down the thick-walled glass tube, through the end of which it is fused. The anode, *a*, is a brass cylinder fitting tightly

within the glass tube, and terminating 12 mm. behind the cathode disc. It is connected by a wire fused through the glass at l , with the other terminal of the induction coil, which is also connected to earth. The end of the tube

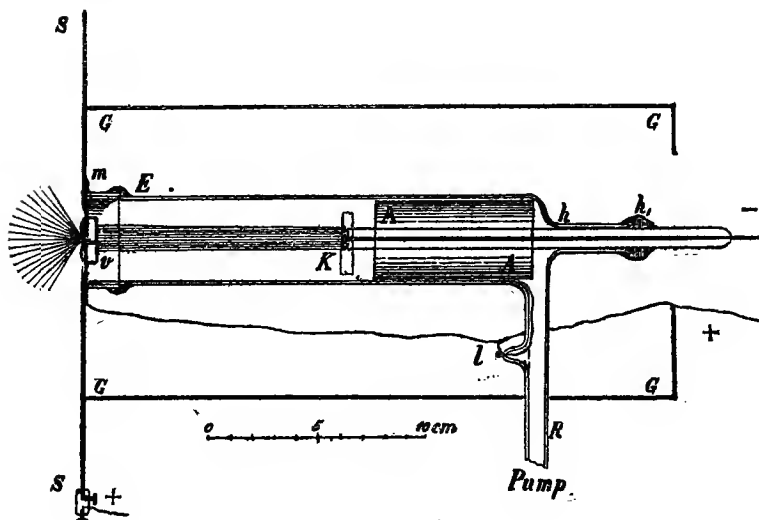


FIG. 8.

is covered by a metal cap, perforated at its centre by a hole 1.7 mm. in diameter, over which is cemented a thin disc of aluminium (.00265 mm. thick), forming the *window* already referred to.

The disc and capsule are in metallic contact, and are connected to the wire. To prevent the window acting as an anode, and thus becoming corroded, it is screened at the back by a perforated metal cover, *v*. The whole tube is enclosed in a sheet metal case *G*, earth connected, and leaving an opening opposite the window. In Lenard's experiments the tube was kept permanently connected to the pump, and exhaustion was continued until—using a 15 cm. spark coil with 4 accumulators—the sparking distance between the balls of the discharging rods was about 3 cm., at which stage the radiations through the window reach their maximum intensity. To avoid unduly heating the tube, the current was only passed during the actual period of the experiments. By means of this apparatus it was possible to study the properties of the cathode rays in the air, in various gases, and in vacuo.

By making the whole tube of ebonite and, as before, making the window the anode, des Coudres (*Wied. Ann.*, 1897, p. 134), was able to obtain the rays satisfactorily at a pressure of 0.2 mm., and it was found that a high potential

gradient was exceedingly helpful. To produce rays of a highly penetrative character, it was found advisable to put a large spark gap in the circuit, and to so arrange the apparatus that the first oscillation had as large an amplitude as possible.

The intensity of the rays emitted is found to depend upon the electric density at the cathode and their character as shown by their deflectibility in a magnetic field p. 194 solely upon the inverse of the potential difference (Kaufmann, *Wied. Ann.*, 61, 3, p. 544). The form of the cathode pencil in the tube has been investigated by Swinton (*Proc. R. S.*, March, 1897), who employed cathodes of high curvature, so as to get a convergent beam, which was caused to fall upon a movable plate of gas carbon. At low vacua the beam, after converging, becomes rectilinear for a short distance, and then diverges, while at lower pressures the straight portion is longer and the divergent portion may not be present. With a cathode of proper curvature, both the divergent and the convergent beams are hollow, though the latter shows some slight internal lumines-

cence, but the rectilinear portion remains solid. By removing a $\frac{1}{8}$ th section from the cathode, it was found that the luminous patch corresponded to this and not to the remaining $\frac{7}{8}$, as might have been expected, showing that the rays crossed at the focus, but that there was no rotation. This was confirmed by the use of an obstacle placed in the path of the rays from a complete cathode, for when the obstacle was in the divergent cone it stopped the luminescence on the same side of the centre, but when in the convergent cone on the opposite side.

By employing both a convex carbon cathode and anode at very high exhaustions, Swinton (*loc. cit.*) showed a collision between the incandescent carbon particles at the focus, which rendered this luminous when the remainder of the rays were invisible.

Cathode Rays in the air. When the current is passed through the apparatus just described, the air opposite the aluminium window of the tube glows with a feeble light, which extends with gradually diminishing intensity for a distance of about 5 cm. from it, but has no definite boundary. If the field in front of the window

is explored by means of a screen covered with a fluorescent material, it is found that at a short distance from the tube the rays form a bush-like expansion, showing that the aluminium acts towards the cathode rays as a turbid medium (*e.g.* milk) towards light.

If a fluorescent screen is placed parallel to and at 3 cm. from the window, and a wire 2 mm. thick is held at a distance of 3 mm. from the window, no shadow whatever is cast on the screen. As the wire approaches the latter a shadow gradually appears, but it is neither very dark nor definite until the two are practically in contact.

When the screen is held a few centimetres from and parallel to the window, the luminous patch is seen to have an ill-defined core of greater intensity. This rectilinear propagation shows that the rays observed outside the tube are not produced at the surface of the aluminium (*cf.* p. 186), but that they have penetrated and been partially scattered by their passage through this. Lenard found that when a parallel beam of light is allowed to pass into a plain parallel trough containing milk, the beam

expanded in a precisely similar manner, even the central core of more or less parallel rays being visible.

Cathode Rays Among the most interesting and
in vacuo. important observations made in connection with the cathode rays are those relating to their behaviour in extremely high vacua.

It has already been mentioned, p. 170, that if exhaustion is carried beyond a certain point, cathode rays are no longer emitted; so that it is obvious that experiments on the rays in vacuo must be made outside the tube in which they are produced. To effect this, Lenard (*Wied. Ann.*, 1894, p. 225) removes the aluminium disc from the window of his tube, and solders on to



FIG. 9.

the cap a metal case into which is cemented the tapered end of the second vacuum tube, the actual extremity of which is closed air-tight by aluminium foil, through which the rays can

penetrate. The second tube is furnished with two electrodes α and k Fig. 9, that next the window being an aluminium disc of nearly the same diameter as the tube, and having a hole in the centre 2.5 mm. across. The other electrode K is a small aluminium disc.

When the vacuum is about equal to that in the discharge tube, the whole of the glass wall between the window and α glows with a green light, but the corresponding interior space of the tube is apparently dark, and also the rest of the tube wall behind this, except a small patch at the extreme end. The *space* behind the electrode glows with a faint blue light, which was shown by subsequent experiments not to be connected with the cathode rays. The luminous patch at ϕ is obviously caused by the rays passing through the hole in α . It is displaced by the approach of a magnet, and shows that as the air is removed from the tube the propagation of the rays becomes more and more rectilinear.

When the exhaustion is carried to the utmost extreme ($= .000009$ mm. mercury) the blue glow disappears, but the glass between

the electrode and the window glows brightly, and the luminous patch is as bright and more sharply defined than before. It was found that the diameter in millimetres of the patch, at distances varying from 60 to 150 cm. from the window, was always a trifle less than the figure obtained by calculation on the assumption of rectilinear propagation. A similar difference is observed in the case of light.

The velocity with which the rays travel appears to depend very much upon their origin, for J. J. Thomson (*Phil. Mag.*, 1889) gave them a velocity about 2×10^7 cm. per second, while subsequently (*Phil. Mag.*, Oct., 1897) it is stated to be of the order of 10^9 with the higher exhaustions then used.

§ 2. Radiability.

The first solid substances found to be trans-radiable were metals (Hertz), and these only in thin sheets. By selecting those rays which were most capable of passing through metals, Lenard¹ discovered that not only could com-

¹ *Wied. Ann.*, 56, p. 225, 1895.

paratively substantial sheets of metal be penetrated, but also (if sufficiently thin) a number of other substances which are opaque to light. Not one, however, was found which behaved as does glass towards light, or of which a layer more than $\frac{1}{2}$ mm. thick was penetrable by rays of sufficient intensity to affect a fluorescent screen.

Gold, silver, and aluminium foil let the rays pass with almost undiminished intensity, and rolled sheet aluminium $\cdot 027$ mm. thick was just appreciably radiable when held close to the window ; glass $\cdot 02$ mm. thick was just perceptibly radiable, while finely split mica and collodion films were decidedly so. One thickness of tissue paper of any colour cast no shadow on a fluorescent screen, with two thicknesses the shadow was perceptible. Writing paper showed a distinct diminution in radiability, drawing paper, $\cdot 12$ mm. thick, is almost, and cardboard, $\cdot 3$ mm., quite, opaque.

Water is only transradiable in extremely thin layers, but soap films stretched on wire rings cast no shadows until at least $\cdot 0012$ mm. thick.

Gases are far more permeable. In the in-

vestigation of the behaviour of the cathode rays in them, Lenard employed a glass tube, 40 cm. long and 3 cm. wide, cemented on to the window end of his vacuum tube, Fig. 8.

In order to be able to compare the absorbing powers of the different gases, a circular fluorescent screen was constructed, with a short strip of sheet iron as a base to keep it upright, Fig. 10. This could be moved backwards and forwards along the tube by means



FIG. 10.

of a magnet. The side towards the window was covered with aluminium foil, and over this was laid a strip of mica. In order to ascertain the relative penetrability of the gases, the screen was moved backwards and forwards until a point was reached at which the dark shadow of the mica on the screen (observed, of course, from the uncovered side) just disappeared. As in the case of air, all the gases became luminous near the window, and the more

penetrable the gas, the greater was the extent of the luminosity; but in no case did the latter, at ordinary pressures, reach nearly as far as the fluorescent effects.

The walls of the tube glowed brightly, hence the necessity for covering the window side of the screen. No colour effects were observed, but the last mentioned phenomenon was not favourable to their detection. In the case of air, it was found that the presence or absence of dust, carbonic acid, or aqueous vapour, made no difference, neither did it matter whether the air was in motion or not. The following table shows the length of the columns of various gases which the rays are capable of penetrating :—

Gas.	Density.	Length of Column in centimetres.
Hydrogen	1	29·5
Nitrogen	14	6·5
Air	14·4	6·0
Oxygen	16·0	5·1
Carbon dioxide . .	22·0	4·0
Sulphur dioxide . .	32·0	2·3

It is obvious, from an inspection of the

figures, that the penetrability decreases as the density of the gas increases. As would be expected from this, when the pressure of the gas is reduced, the length of the radiation column increases, and the differences between the gases gradually diminish and eventually vanish. The nature of the minute quantities of gas left at such low pressures thus appears to be without appreciable influence on the absorption, as is shown by the following table :—

AIR.		HYDROGEN.	
Pressure.	Length of Column.	Pressure.	Length of Column.
760·0	2·35	760·0	10·6
165·0	8·38	167·0	32·4
40·5	17·1	42·2	56·1
2·7	73·0	3·3	122·0
·074	127·0	·065	126·0
·0083	133·0	·0165	130·0

The above results are not comparable with those in the previous table, as a different tube was employed, and the phosphorescent screen was covered on the window side with four

sheets of aluminium foil, having a total thickness of $\cdot 0133$ mm., and was thus considerably reduced in sensitiveness.

Special experiments were made to ascertain if the glass walls of the tube had any influence on the apparent transparency of the gases, either by preventing (in the case of the high pressure) curvilinear rays from reaching the screen, or (in the case of the low pressure) by reflecting on to the latter, rays with a rectilinear path which would not otherwise reach it. In neither case was any such effect found; it may therefore be concluded that the figures represent the actual relative transparencies of the gases in question, and are uninfluenced by the vessel in which the latter were enclosed.

Dealing with the absorptive power of substances generally, Lenard, as the result of the examination of a large number of bodies, has enunciated the following law: "The ratio between the absorbing capacity and the density for all media, is approximately equal to one and the same constant for any one kind of cathode rays." This holds good approximately, but with differences considerable enough to require

some further explanation, through the widest possible range of density, as the following table will show :—

Substance.	Absorptivity, 1 cm.	Density.	Absorptivity.	Density.
Hg. Pressure.				
Hydrogen at 3·3 mm.	·00149	·000000368	4040	
Air „ 7·8 „	·00416	·00000125	3330	
Hydrogen „ 760 „	·476	·0000849	5610	
Air „ 760 „	3·42	·00123	2780	
Sulphur dioxide „ 760 „	8·51	·00271	3110	
Collodion film. . . .	3310	1·10	3010	
Paper	2690	1·30	2070	
Glass	7810	3·47	3160	
Aluminium	7150	2·70	2650	
Mica	7250	2·80	2590	
Gold leaf (impure) .	23800	8·90	2670	
Silver.	32200	10·5	3070	
Gold	55600	19·3	2880	
Average : 3200				

In passing through an absorbing medium the intensity of the rays will diminish with the distance from the window, (1) because of the spreading of the rays in all directions ;

i.e., the intensity I will vary *inversely* as the square of the distance. (2) on account of the absorption, for which the simplest possible hypothesis is that equal fractions (the amount of which depends on the nature of the particular medium) are absorbed in equal distances, which may be expressed by $I = I_0 e^{-ar}$, a being the constant characteristic of the medium. Of course both causes always act simultaneously, so that if I_0 represent the intensity of the rays as they leave the window, the intensity at any distance r may be found by means of the following relation : $I = I_0 \frac{e^{-ar}}{r^2}$

Examination of the emergent beam shows that on the whole the rays proceed from the transmitting surface in a normal direction, as pointed out by Villard (*Bull. Soc. Franç. Phys.*, p. 2, 1897), and this appears to show that they do really traverse the obstacle, for if they were absorbed on one face and the impulse caused others to radiate from the opposite face, these would be emitted in all directions, and not in a normal direction only.

§ 3. Fluorescent and Phosphorescent Effects.

Solids.—The phosphides of the alkaline earths,¹ calc spar,¹ and uranium glass glow brightly, when near the window, but at 6–8 cm. the luminosity disappears, as it does with common glass and flint glass at a less distance. Specimens of quartz and rock salt became luminous (blue) only when close to the window. An oxide of aluminium produced by the corrosion of that metal glows partly with a grey-green and partly with a blue colour, and probably the faint luminosity of the window is due to the oxidation of the metal by ozone. Platinocyanides of various kinds display colours corresponding to those which they exhibit under the influence of the ultra-violet rays, and uranium glass gave its characteristic spectrum (Lenard). Salts of manganese, lithium, cadmium, and strontium luminesce brightly, also anthracene and hydroquinone, salicylic benzoic and hippuric acids.²

For experimental purposes a screen made by

¹ These also phosphoresce brightly.

² W. Arnold. *Zeit. für Elektrochemie*, 1896, 602–604.

spreading with a brush on tissue paper melted pentadecylparatolylketone has been employed. Such a screen is semiradiable, and under the influence of the rays emits a bright green light, which does not persist after removal of the exciting cause. Eosin gelatine, which with light is strongly phosphorescent, is unacted upon. Bodies incapable of fluorescence with light, such as metals, mica, crystals of gypsum and sulphur, do not fluoresce with the cathode rays.

Liquids as a rule are inactive. Thus eosin, fluoresceïn, magdala red, sulphate of quinine, and chlorophyll, which all fluoresce with light, are only very feebly, if at all, excited. In the solid state the above bodies behave similarly, except the quinine salt which glows with a brilliant blue colour. Petroleum and other fluorescent hydrocarbons exhibit a blue colour, as with light.

§ 4. Reflection and Refraction.

Cathode rays in the tube appear to be reflected according to the same laws as light, considering the divergence of the cathode beam

on reflection from the anticathode in the focus tube (p. 208), Segúy (*C.R.*, 122, p. 134) has also stated that he has obtained regular reflection with external rays.

According to the experiments of Wiedemann and Ebert (*Sitz. Phys. Med. Erlangen*, Dec., 1891), diffuse reflection occurs in most cases, but it appears to become more regular when the electric force is parallel to the surface.

§ 5. Interference and Polarization.

A quasi-interference has been observed by Jaumann between two cathode streams; the interference takes the form of a surface, and is only seen when the joints of the tube are perfect and the resistance is changed. The surfaces tend to move and bend round the cathode (*Sitzungsberichte Wien.*, July, 1897). These observations have been much questioned.

No experiments on the polarization of the rays have led to positive results.

§ 6. Electrical and Magnetic Effects.

When the negative rays fall upon an insulated substance within the tube it receives a positive charge (Crookes); when however the cathode rays fall upon a substance outside the tube no appreciable charge is acquired, but if the body is electrified it will lose its charge (Lenard). The effect is not an electrostatic one, for if the electrified body and electroscope are surrounded by a wire gauze cage, or a sheet of aluminium foil is interposed, a loss of charge will be still observed, while if the rays are prevented from falling upon the plate no change takes place; this effect is observed at a far greater distance from the window than fluorescence.

Charge carried by Rays. To measure the charge carried by the rays, Perrin (*C.R.*, 1895, p. 1130) devised an apparatus, in which two concentric cylinders were placed in the vacuum tube, with the end facing the cathode so far covered, that rays falling on this could only enter the *inside* of the inner cylinder. This was itself insulated from the outer and connected to an electrometer,

while the outer was connected to earth. It was found that the charge rose to a certain maximum value, which was probably determined by the rate of leakage through the gas between the cylinders.

Perrin considered that his experiments were definitely in favour of the radiant matter theory, but it was argued that the charge might not be produced by the particles at all, but by a vibration following the same path. This objection was met by J. J. Thomson (*Phil. Mag.*, Oct., 1897), who deflected the rays by a magnet *on to* the end of the cylinder, and it was observed that there was a deflection of the electrometer when and only when, the phosphorescent patch, which marked the place where the rays struck the glass, came over the opening in the cylinders.

Electrostatic deflection. The first attempts to measure the effect of an electric field upon the rays were not successful (Voller,¹ Hertz²), although large fields were used; but somewhat analogous phenomena have been observed, such as the mutual repulsion of two cathode streams, by

¹ Wiedemann, *Handbuch*, 4 A, 436 (1880).

² *Wied. Ann.*, 19, p. 809 (1883).

Crookes (*Phil. Trans.*, 1879, p. 652), which has been shown by Majorana (*Rend. Acc. Linc.*, 1897, p. 183) to be independent of the potential difference, but to vary with the pressure. This, however, is only a special case of the phenomena observed by Goldstein, who showed that any object brought near the outside of the tube close to the anode caused cathode rays to be projected on to the opposite side of the tube, and that these caused a deflection of, and were deflected by, the rays from the cathode. The effect of causing a current to traverse the cathode transversely was investigated by Barr and Phillips (*Elec.*, 38, p. 498), who found that the shadow of a rectangular obstacle became enlarged on the side towards which the current was flowing in the cathode, and also that when two similar obstacles (*Elec.*, 38, p. 530) were maintained at different potentials, the one which was positively electrified gave a smaller shadow, and the other a larger than normal, especially when the latter was earth-connected. In both cases there was a slight shift of the whole shadow in the direction in which the current was flowing.

By employing very feeble rays, Jaumann (*Elec.*, p. 343, 1896) was able to get an electrostatic deflection which was extremely sensitive to small variations in potential. The tube was immersed in machine oil, with the anode in the oil, and it was found that the best results were obtained when the phosphorescence at the end could only just be seen. A deflection of the rays was caused by an electrified glass or ebonite rod, and when the tube was placed between plates charged to a potential difference of 6,000 volts, the rays were attracted for a *short time* to the *negative* plate, an opposite result to the one expected.

It has been shown by J. J. Thomson that the conductivity of gases when exposed to these rays falls off rapidly at low pressures, and he was hence led to try the effect of an electric field. For this purpose the rays were caused to pass between two parallel plates contained in the tube and connected with a source of potential.¹ It was found that they were always *repelled* from the negative plate, and that

¹ *Phil. Mag.*, Oct., 1897.

they were not all deflected equally, the series of phosphorescent bands obtained closely resembling the magnetic spectrum (p. 196). The deflection was not permanent at pressures near the limiting one, since the medium becomes a partial conductor after a certain time.

**Behaviour
in Magnetic
Field.**

The effect of a magnetic field upon the negative rays has been known for many years, for Hittorf (*Pogg. Ann.*, 1869, p. 213) showed that they would twist into spirals, and that in some ways they behaved like a flexible current (see the positive column) under the same conditions. The path assumed by the rays is always that which would be taken by a negatively charged particle moving from the cathode, and is such that the normal magnetic force $H = mv^2/\rho$, where ρ is the radius of curvature of the path, m and v the mass and velocity of the particles. Under certain conditions the magnetic force causes a continuous rotation of the rays, as observed by Crookes (*Phil. Trans.*, 1879, p. 657); but the rotation took place in the opposite way to the one expected, that is, opposite to that which would have been taken by a wire conveying a

current in the direction in which the rays were travelling.

The helical path followed by the rays was also demonstrated by Fleming (*Elec.*, 38, p. 864), who, when using an alternating field, observed that the shadow of the cross in the common form of Crookes tubes oscillated about its normal position and appeared to keep time with the induction coil, showing that the helix might turn either way. With constant fields produced by a wire ring conveying a current and surrounding the tube between the cathode and the cross, there was no rotation, but the shadow diminished and finally disappeared. It was replaced by a larger shadow, each arm of which was more sickle shaped (Fleming, *Elec.*, 38, p. 302), showing a twist in the path of the rays.

Lenard observed that the fluorescent patch produced on an external screen by the cathode rays, and which was normally circular, became elliptical when the rays traversed a magnetic field, and that the bright centre was deflected less than the outer portions. When the rays were passing through vacuo, it was found that

the deflection was the same all along their course, and that those *produced* in high vacua were less deflected and spread out than others. The separation of the rays of various kinds, by means of a magnetic field, was first accomplished by Birkeland (*Elec. Rev.*, June, 1896). The rays, which were sent through a slit, and which would thus normally give a single band on the glass wall, under the influence of a transverse magnetic field, separated into a series of parallel bands at various distances from one another and on the same side of the original position. This was called a magnetic spectrum, and on the particle hypothesis indicates that the rays are travelling with different velocities, those which are the least deflected being the most rapid.

The investigation has been extended by J. J. Thomson (*Phil. Mag.*, Oct., 1897), who has photographed the entire paths of the rays after leaving the slit, the uniform field being produced by the coils of a Helmholtz galvanometer. When the pressures of the gases were so arranged that the potential difference remained constant, it was found that the paths

were circular and exactly the same, while even the peculiarities of the magnetic spectrum were common to all, showing that they depended upon the construction of the tube alone. It has also been shown by Majorana (*Rend. Acc. Linc.*, p. 16, 1897) that the deflectibility of any particular band varies inversely as the potential difference, and that the nature and pressure of the gas, the presence of spark gaps, etc., have no influence.

In nearly all cases there are certain rays which appear to suffer no deflection, but which otherwise comport themselves like cathode rays, discharging negative electricity and producing phosphorescence (Battelli and Garbasso, *N. Cim.*, 4, 4, p. 129), though it has been suggested by J. J. Thomson that they are *molecules* of gas projected with high velocity from the slit.

The effects so far considered have been those produced by transverse fields alone upon the cathode rays, and these differ most markedly from the effect of longitudinal fields. The discharge is generally somewhat altered, and is usually facilitated by the latter; and at

low exhaustions when the cathode rays are produced, these are drawn into a blue cone with a whitish core when their course is towards the magnetic pole, and are largely stopped when the reverse is the case.¹ Under all circumstances the discharge is facilitated owing to a decrease in the resistance. This cone can, under suitable conditions, be made to diverge after convergence, and, as in the case of a concave cathode (p. 174), both the divergent and convergent beams are hollow (Swinton, *Elec.*, April, 1897), though the original parallel beam was solid.

The cathode rays possess the same power as the ultra-violet and the X rays, of causing those gases which they traverse to become conductors of electricity, as shown by J. J. Thomson (*Phil. Mag.*, Oct., 1897). The pressure in one case was as high as possible, in order to keep a considerable mass of the gas under the influence of the rays. It was arranged so that the phosphorescent patch at the end of the tube could just be seen. The rays were passed between two parallel plates, one of which was

¹ Swinton, *Proc. Roy. Soc.*, 1896, p. 179.

connected to the earth, and it was found that the current tended to a maximum, and that the rate of leak was nearly independent of the sign of the charged plate. The current did not last, however, and the change in potential due to it was not more than 6 in 400 volts.

At very low pressures, on the other hand, there was a more rapid leakage when the plate was positive than when negative, and it appeared to be rather greater when the potential difference was high than when low.

§ 7. Chemical Effects.

The rays have a marked effect upon most of the alkaline halides and on some of the halides of the earths, producing colour changes, which in dry air and in the dark last for several months, but which are destroyed by damp and heat, the salt returning to its original condition. Lithium chloride becomes violet, and is one of the most permanent (*Wied. Ann.*, 1895, p. 371), while sodium chloride can be obtained by suitable means in a yellow and a grey condition, the former turning red when heated, and the latter blue (*Sitz. Berlin.*, 1895, p. 1017).

These modified salts are all extremely sensitive to the action of light, which effects a destruction of the colour, as also does a very intense beam of rays.

The cathode rays act energetically on sensitized papers and plates. At a short distance from the window (*v.* Fig. 8), a plate was found to blacken completely on development after a few seconds' exposure. By prolonging exposure a sensitive plate was affected through a thickness of material which appeared perfectly opaque if judged by a fluorescent screen. A layer of cardboard, 3 mm. thick, was thus penetrated after an exposure of two minutes. Iodine paper was found to turn blue on exposure to the rays, but this was possibly due to the presence of ozone. (*See Physiological Effects.*)

§ 8. Physiological Effects.

Cathode rays do not affect the eye and produce no sensation on the skin. A peculiar taste is perceived by the tongue, but this is ascribed to ozone, which can be plainly smelt.

§ 9. Theories.

There is perhaps no other modern example of a phenomenon which has received so much attention from noted investigators as have the cathode rays, and yet there are two rival schools which bring forward utterly different hypotheses, and back up their theories by accumulations of evidence. There is, moreover, another theory which has been advanced by Jaumann, and which, from the circumstantial evidence adduced in its favour, seems of some importance.

The two principal rivals have almost a racial distinction, nearly the entire body of German physicists adhering to the view that the cathode rays are ethereal vibrations, while the English adhere as firmly to the view that they are particles of some nature projected from the cathode. The supporters of the first theory consider that Lenard's experiments, in which he showed that the cathode rays are propagated in straight lines through a vacuum so free from matter that an electric spark would not pass, must, without some special theory, be considered as proving the case.

Wiedemann first supposed that the rays were ultra-violet radiations with a frequency of about 10^{15} or 10^{16} , subsequently, however, adopting a view which ascribes them to vortex motions. It is found that oscillations in the cathode, which take place normally, and with an amplitude proportional to the frequency, assist the discharge, this being considered important, and many data have caused the following (among others) to hold the view that the rays are some kind of ethereal vibration: Weidemann (*Wied. Ann.*, ix., p. 159; x., 251; xx., 781); Hertz (*Wied. Ann.*, xix., p. 816), and Goldstein (*Wied. Ann.*, xii., p. 264).

J. J. Thomson has determined the velocity of the rays, and on the particle hypothesis the relation of mass to charge e/m carried by them. The first has been considered on p. 196, and if this variation in velocity is substantiated by further evidence, it would seem an important argument, for the only ethereal vibrations with which we are conversant do not vary their velocity with their wave length, while one would expect that a high difference of potential would

cause the emission of particles of a less density than a low one.

The ratio e/m was deduced from measurements of the charge carried by the rays (p. 190) by measurements of the *heat* produced in a thermo-electric junction inside the cylinder, and by the curvature under a magnetic force. The result obtained was about 10^{-7} for hydrogen, while the same quantity in electrolysis is about 10^{-4} , and J. J. Thomson (*Phil. Mag.*, Oct., 1897) suggests that this is due to two factors; one that the "corpuscles" are integral portions of atoms, and the other that they each carry a larger proportionate charge due to the sundering of these ultra-chemical bonds. The idea is also put forward that these may be the primordial atoms required for Prout's hypothesis.

The theory advanced by Jaumann¹ differs from the usual ethereal theories in that it calls in the aid of *longitudinal* waves. Jaumann considers that the fact that the cathode rays have a great discharging effect when incident at right angles, shows that they have a large longitudinal component, and that their be-

¹ *Wied. Ann.*, 1896, p. 147; *Electrician*, vol. 36, p. 629.

haviour in a magnetic field entirely coincides with this view. According to his theory, the rays can only be regularly reflected when the electric force is parallel to the reflecting surface, and that in all other cases irregular diffusion will occur; this was to some extent borne out by the experiments of Wiedemann and Ebert (cf. p. 189).

CHAPTER III

THE RÖNTGEN OR X RAYS

SINCE Prof. Röntgen's announcement of his discovery to the Würzburg Physico-Medical Society in November, 1895, a vast amount of work has been carried out in endeavouring to bring this phenomenon into line with others with which we are more conversant; but up to the present, although a quantity of data of all kinds have been collected, no very definite conclusions can be formed. The discovery of the X rays has had a marked influence on the subject of obscure radiation, and has resulted in the discovery and investigation of various other forms, which will be dealt with subsequently.

In the former chapter a short summary of our knowledge with regard to the nature and properties of the cathode rays has been con-

sidered, and it will be seen that in many cases their properties so nearly resemble those of the X rays, that the connection between their methods of production seems more than accidental.

§ 1. Production.

The X rays were first produced by Röntgen with a Crookes' tube of somewhat higher exhaustion than that which is usually employed for the production of the cathode rays.

His results were excellent from the beginning, and it was some time before as satisfactory ones were obtained by other workers. This may have been partly due to the fact that he was employing a very hard glass, which we shall see later is considerably more conducive to good results than the softer varieties.

Later experiments have shown that many small data largely affect the efficiency of the tube as a source, and have also shown that the tube is not the *only* source of these rays. They were obtained by Lord Blythwood quite markedly from the terminals of a frictional electric machine, but the amount obtained was

much less than would have been obtained with a tube, if the same energy had been expended in both cases. They have been sought for in sunlight and the electric light, but apparently do not exist in either.

The practical method of production is, however, still a vacuum tube supplied with some form of suitable current, which must be of a rapidly intermittent nature. Various ways of obtaining a suitable current are given on page 156.

**The Vacuum
Tube.**

The general principle of the vacuum tube is the same for both the cathode and Röntgen rays, but for the efficient production of the latter certain modifications are necessary. The best results are obtained by a careful adjustment between the form of the tube and the pressure of the gas in it.

Any vacuum tube with a suitable exhaustion and current can give out X rays, and at first the usual forms of Crookes' and Hittorf's tubes were used for this purpose. Certain Geissler's tubes also can emit them; but the result is feeble, owing to insufficient exhaustion. The

form most generally used at present is that devised by Herbert Jackson, and known as the "focus tube." In this the concave cathode, which had previously been used in some of Crookes' tubes, is so arranged that its focus coincides with the centre of a flat platinum terminal, either to be used as an anode, *i.e.* connected with the positive terminal of the source of potential, or as an anticathode. In either case its plane is at an angle of 45° with the plane of the cathode. In consequence of the "focussing" action of the latter, the cathode stream is caused to impinge on a small portion of the side wall of the tube, thus giving a small centre of origin in place of the diffused sources which are usually given by a Crookes' tube; but, as is well known, glass under the continued action of the stream becomes "tired," and it seems that at the same time the yield of X rays falls off.

To reduce this difficulty many devices have been suggested, and some have been used, such as making the anode (or anticathode) rotate, and hence causing the stream to impinge on different portions of the tube wall, or, as is preferable

in practice, by allowing the tube to rotate about the fixed anode as an axis, so that the direction of the resulting X rays remains constant. Recent improvements have, however, so reduced the times of exposure required that trouble now seldom arises from this cause.

For the alternating currents from a Tesla transformer the better forms of tube have two concave terminals connected to the transformer, and two, or better, one, anticathode so arranged that the stream will have the same resultant direction with the two directions of the current. Puluj¹ has described a tube having an oblique anticathode of mica, covered with green CaS extending completely across it. The form was devised in 1889 for the cathode rays, and is said to require very short exposures. Certain experimenters also use an aluminium anticathode, which allows the rays to pass through it owing to its radiability. Others again use annular anodes in long cylindrical tubes, but no particular advantage seems to have been derived from these arrangements.

¹ *Proc. Phys. Soc.*, 1896.

The use of external caps of aluminium¹ appears in some cases to be useful, and one experimenter² obtained increased efficiency by having the glass very thin at the point of impact. The same principle was used by F. Neesen,³ who employed a bladder system. The action of the cathode stream on this, however, causes the evolution of carbon monoxide, which has to be continuously pumped away. A tube of a markedly improved form is described by Davies (*Nature*, June, 1896). In this the bulb is made entirely of metal, and is itself the anticathode. The front is made of aluminium, the cathode being formed by a concave metal mirror behind a smaller plate. The anode and cathode are, of course, thoroughly insulated.

Another form has been found very efficient by Wood (*Phys. Rev.*, 5, p. 1, 1897). In this a small and very intense source is obtained by the use of an arc discharge between two minute platinum balls in a highly exhausted vacuum tube. When the balls are at a distance of

¹ P. Seyman, *Zeit. Instrum.*, 16, p. 151.

² Calcardeau, *Bull. Soc. Franc. Phys.*, 82, p. 1.

³ *Ver. Phys. Ges.*, Berlin, 15, p. 80.

about 1 mm., the Röntgen rays come principally from the anode. The exhaustion required for the efficient production of the X rays depends somewhat on the class of rays required, but with the more usual forms of tube, such as the focus tube, is considerably higher than is necessary for the cathode rays. In these tubes it has been noticed that the dark space (*b*) Fig. 7, p. 164, has to occupy the whole tube. At this stage in tubes made of German glass the walls glow with a yellow-green fluorescence, which must be free from any shade of blue, as this accompanies an insufficient vacuum. With tubes of other forms these conditions do not necessarily apply, so that the only sure test of the efficiency of a tube is to observe the radiation from it with an actinometer (p. 244).

The radiation from any source is not homogeneous, and can be made to change its character by altering either the internal or external conditions. It is probable that these changes do not so much cause the emission of new rays, as alter the ratios between the intensities of the groups existing in the radiation.

At least three different groups of X rays have been distinguished ; but this may only mean that three varieties of the same phenomenon have been found ; in fact, the continuous manner in which these three forms can change one into the other makes it extremely probable that intermediate forms exist and that there is

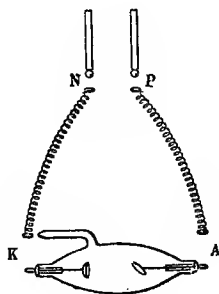


FIG. 11.

no other difference between them than one of magnitude, giving them the same relation as one colour or sound to another.

T. C. Porter¹ has found a simple method by which a certain change from one form to the other can be easily effected.

In Fig. 11 *N* and *P* are spark gaps be-

¹ *Nature*, November, 1896.

tween brass knobs, two of which are attached to the source of electrical energy, and the opposite two carry wires connecting them to another pair of knobs at the spark gaps, K and A , at the terminals of the tube. The following arrangements of the spark gaps and of the resistances are made for the three varieties he recognises, for

X_1 rays, N and P , are each $\frac{1}{2}$ in. A is made very small, and there is a resistance equal to that of the secondary of a $4\frac{1}{2}$ " coil across K .

X_2 (non-penetrative). Keep A very small, and make $N=P$ and just large enough to avoid outside sparks, then put a string across spark gap K and separate the terminals so that all the current goes through the string.

X_3 (very penetrative). Make the spark gap K about $\frac{1}{4}$ in., and the gaps A , P , and N as for the production of the X_1 rays.

W. M. Stine¹ states that rays produced by the impact of the cathode stream on glass have more penetrative power than those from metal impact, although the latter cause a brighter fluorescence. The character of the rays can

¹ *Elec. World*, 28, p. 383, 1896.

be also altered by temperature and by a magnetic field.

Temperature has a marked effect, as has been shown by several observers, most of whom have tried the effect of heat. Edison, however, records experiments at the freezing point by immersing the tube in mineral oil inside a jar cooled to zero centigrade. The rays produced were extremely penetrative, even traversing $\frac{1}{8}$ " of *steel*, and hence by analogy with above they would be X_3 rays. T. C. Porter first produced the X_2 rays by heating the tube, and numerous other workers have employed the same method. This increases the power of the tube for producing X_1 rays up to a certain limit, and then decreases it. The heat is best supplied by the flame of a small spirit lamp in the angle between the cathode wire and the tube,¹ while heating the cathode is also beneficial.²

The efficiency of tubes can be increased, and the risk of fatigue avoided, by stopping and reversing the current for five minutes during or

¹ Crump, *Nature*, July 9, 1896.

² S. P. Thompson, *Phil. Mag.*, Aug., 1896.

after a long exposure. The same result can, however, be obtained more conveniently by using an insulated copper ring outside the tube, just out of contact with it, and placed concentrically with the edge of the cathode. A terminal of an earth-connected wire is then supported within a small fraction of an inch from the wire ring, so that minute sparks pass from one to the other.¹

If the tube is placed so that they travel along lines of magnetic² force, the rays seem to be much condensed, the same tube under these conditions giving a much more intense radiation, but the tendency is to produce X_3 rays.

§ 2. Reflection and Refraction.

Reflection. One of the simplest and most fundamental properties of all forms of radiation is that of reflection from plane surfaces, and some of the earliest observations were directed to the observation and measurement of this for the X rays; contrary to expectation, and yet consistent with their

¹ T. C. Porter, *loc. cit.*

² Swinton, *Proc. R. Soc.*, June 4, 1896.

powers of penetration, the X rays seemed at first to defy reflection¹; subsequent experiments, however, have shown that the phenomenon does occur in an irregular manner, resembling the diffusive reflection of light from powders and from surfaces like ground glass.

Of the three properties of a surface mentioned in a former chapter, on which the reflection of light has been found to depend, only two have any influence in the case of the Röntgen rays, the condition of the surface being practically without effect.

The angle at which the reflection has usually been measured is 45° , the tube being placed so as to throw the rays at this angle on to the surface of which the reflecting power is to be estimated, while between these some opaque object, such as wire gauze, is placed, and the image is received on a photographic plate also at an angle of 45° to the reflecting surface.

The nature of the material of which the surface is composed, has considerable influence on the amount of reflection. Thus Rood²

¹ Röntgen, *Sitz. Phys.-Med. Würzburg*, November, 1895.

² *Am. J. of Science*, 2, p. 173, 1896.

states that platinum reflects $\frac{1}{280}$ part of the amount incident at an angle of 45° , while Tesla (*Nature*, April 30, 1896) finds that zinc reflects 3% and that the following metals increase in their power of reflecting the rays in the order in which they are placed, viz., silver, copper, iron, tin, lead, zinc, magnesium. Sodium, and perhaps lithium would probably be still better, but have not been tried. This order is somewhat remarkable, as one would not expect that the most radiable metals would be those with the greatest reflecting power. Dwelshauers-Dery¹ does not consider that the X rays are reflected as such, and states that the order of increasing reflecting power for the metals is, aluminium, lead, gold, platinum, iron, brass, copper, tin, zinc.

Joly² found reflection from wood, glass, lead, mercury, but he does not give any idea as to the relative amounts; though he pointed out that at glancing incidence the amount of reflection from most substances assumes considerable proportions. This property has been

¹ *Bull. de l'Acad. Roy. de Belgique*, No. 6.

² Dublin Univer. Exper. Science Asso., March, 1896.

utilised for the purpose of concentrating the rays,¹ by causing them to pass through a conical tube of zinc or lead, of an angle of less than 30° , the large end being nearest to the source. A marked increase in intensity is observed, when compared with the unaided emission of the tube.

Lord Blythswood (*Proc. Roy. Soc.*, March, 1896) obtained radiographs by reflection of several opaque objects in about twenty minutes. The mirror was made of speculum metal, and the rays traversed a thin aluminium screen after reflection, behind which were the objects placed on cardboard covering the photographic plate. It is clear that this experiment is not capable of distinguishing between regular and diffusive reflection.

Wohler and Walter (*Wied. Ann.*, 61, 1, p. 88) find that the reflecting powers of the elements increases in passing from groups i. to iv. in the periodic system, and then decreases again, and other observers² have noticed that glass and selenite reflect better than metals.

¹ Joly, *loc. cit.*, also Tesla.

² Malagoli and Bonacini, *Rend. Acc. Linc.*, 5, 1, p. 327.

Refraction. A number of attempts have been made to measure the indices of refraction of substance to the X rays, but most have only resulted in fixing more or less accurately the difference between the index (if one exists) and unity. All the substances tried appear to possess an almost identical refractive index which in every case is nearly unity. This would be accounted for if we suppose that the rays are vibrations of an exceedingly small wave length, so small that they occupied the position represented to the right of A in Fig. 4, p. 102, for all substances.

As specimens of the results obtained we find that Gouy¹ gives it as not more than $1 \pm .000005$, a quantity almost outside the limits of measurement. He used the linear source obtained by the edge of the platinum cathode, projecting the shadow of a fine platinum wire upon his sensitive plate; while F. Beaulard² put the value for potassium at less than 1.00001 , and Wohler and Walter (*loc. cit.*) as certainly not differing from unity by more than $\pm .0002$ for the diamond. However Czermak found a

¹ C. R., 122, p. 1195.

² C. R., 123, p. 381.

slight displacement with an aluminium prism, and Precht (*Wied. Ann.*, p. 333, 1897) gives $n=1.0043$ for flint glass, and 1.004 for arragonite.

§ 3. Penetrative Power, Radiability.

The power possessed by the X rays, of penetrating bodies opaque to light, was the cause of their attracting so much attention from the general public, and although other forms of radiation (pp. 77 and 85), pass with equal facility through opaque substances, the effects produced are not nearly so striking and do not lend themselves to such sensational applications. Röntgen, in his first paper, mentioned a large number of substances with which he had experimented, and he has shown that density and thickness are the two factors on which the transparency mainly depends, but that at the same time there are others, for the product of the density multiplied by the thickness gives no index whatever of the opacity of a body. Thus, taking such thickness of the following metals as were apparently equally pervious to the rays, he obtained the following results :—

	Relative thickness.	Density. Product.		At : wt : Product.	
Platinum .	1	21.5	21.5	195	195
Lead . .	3	11.3	33.9	207	621
Zinc . .	6	7.1	42.6	65	390
Aluminium	200	2.6	520.0	27	3400

Other investigators have recorded similar observations, and the following tables show the relative radiabilities of a large number of substances and groups of substances.

I. Elements. The results obtained by Battelli and Garbasso (*N. Cim.*, 4. 3, p. 40) are plotted against the corresponding densities and atomic weights on p. 225 and p. 230. Other results have been given, thus $K=1$, $Na=2$, $Li=20$ are equivalent thicknesses,¹ also $Pt=2.5$, $Pb=2.9$, $Sn=10$, $Al=250$, $Mg=360$,² and the relative radiabilities $S = P_{\beta} = Al > Mg > B = Ca = \text{air}$.³

¹ Marungoni, *Rend. Acc. Linc.*, 5. 2, p. 403.

² O. Zoth, *Wied. Ann.* No. 6.

³ Novák and Šulc, *Zeit. Phys. Chem.*, 1896, p. 489.

II. Oxides.¹

			Density.	Molecular weight.	Colour.
Al ₂ O ₃	very radiable.	...	4'00	...	103 ... white.
Cr ₂ O ₃	semi	„	4'99	...	153 ... green.
Fe ₂ O ₃	non	„	5'13	...	160 ... brown.
Mg O	very	„	3'42	...	40 ... white.
Zn O	semi	„	5'47	...	81 ... white.
Hg O	non	„	11'13	...	216 ... red.

III. Sulphates. In order of radiability.²

Li. Al. Mg. Na. Cd. Ca. Sr. Ba. Mn. Zn.

IV. Sulphates, arsenates and phosphates.³

Numbers give radiabilities (paraffin = 10).

H ₂ K As O ₄	5	Mg SO ₄ Am ₂ SO ₄ 6Aq	} 2
H ₂ Am As O ₄	4	Zn SO ₄ Am ₂ SO ₄ 6Aq	
Ni SO ₄ Am SO ₄ 6Aq	} 3	Co SO ₄ K ₂ SO ₄ 6Aq	
Mg SO ₄ K ₂ SO ₄ 6Aq		Co SO ₄ Am ₂ SO ₄ 6Aq	
Ni SO ₄ K ₂ SO ₄ 6Aq	2'5	H ₂ Am Po ₄	1

V. Formates and acetates in order.⁴

Li. K. Na. Ca. Zn. Al. Pb.

¹ Ackroyd and Knowles, *Journ. Soc. Dyers and Cleaners*, April, 1896.

² Arnold, *Zeit. f. Electrochemie*, 1896, p. 602.

³ Goodwin, *Nature*, April, 1896.

⁴ *Chem. News*, Nov., 1896.

VI. Pearls and crystalline alumina (sapphire, oriental ruby) are more radiable,¹ diamonds and jet² less radiable than their imitations.

VII. Silicates.³ Glass consisting of Na, K, Ca silicates only is the most radiable. German and uranium glass are much less so, and show a greenish fluorescence. Plate glass = 29 where tinfoil = 1. Lead crystal is very non-radiable and gives a blue fluorescence.

The observations combine to show that the radiability of a substance is a very complex function, and that no general relation can be found between its chemical and physical properties, and the amount of absorption it will exercise.

The four factors which have the greatest influence on the radiability of a body are :—

- | | |
|---------------|---------------------------|
| 1. Density. | 3. Molecular weight. |
| 2. Thickness. | 4. Chemical constitution. |

It is necessary to remark here that sufficient care has not been taken by some workers to describe the conditions of their experiments,

¹ Burgnet and Gascard, *C. R.*, 122, p. 729. ² *Ibid.*, p. 457.

³ Chabaud, *C. R.*, 122, p. 603.

so that where results disagree, it is practically impossible to account for the discrepancy.

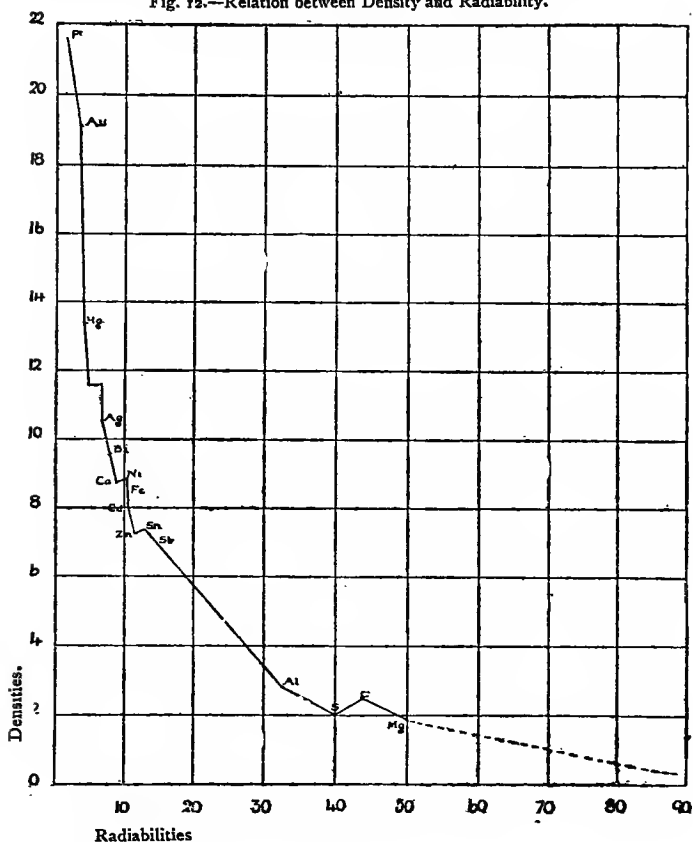
Reference to page 213 will show that by altering the pressure and temperature in the tube, the character of the rays may be profoundly modified, but the data and remarks which follow will be considered to apply to the X_1 rays as defined by Porter, and reference to the tables will show that the relative radiabilities found by different observers vary enormously. Thus, while all approximately agree in the relation between tin and platinum; one finds magnesium seven times more nonradiable than the other. The results are little likely to be definite until some means can be found of determining easily and rapidly the exact type of rays used. Various actinometers have been suggested for this purpose, depending on the penetrative power through aluminium, or the fluorescence produced in comparison with that given by a standard light (Roiti, *Mem. Accad. Linc.*, 1896).

**The Influence
of Density.**

It will be seen on reference to the tables that the radiabilities of substances have some relation to their densities,

especially with the more elementary ones ; for

Fig. 12.—Relation between Density and Radiability.



the results referred to in Table I., when

plotted against the densities as in Fig. 12 take the form of a rectangular hyperbola, and it is probable that in many cases some such relation would obtain, but it is less well-marked with the Röntgen than with the cathode rays (p. 185).

Röntgen and others considered that the radiability of substances is independent of their homogeneity; but more recently it has been stated that loose powders are more nonradiable than the same powders when compressed (Zoth, *Wied. Ann.*, 58, p. 344, 1896), and also the converse. With minerals, although those of densities greater than 5, are comparatively nonradiable, no general rules can be found among those of less density (C. Doelter, *Chem. Zeit.*, 20, 17, p. 183).

The
Thickness. The absorption of the X rays by substances is not a linear function of the thickness, although in a few cases the ratio seems to approach one of simple proportion.

The following substances are stated to be nonradiable for the thicknesses given, but these numbers must not be considered as really giving their relative radiabilities. 2 mm. platinum

(.01 mm. easily traversed); 10 mm. mercury (.01 mm. ditto); 18 mm. lead; 30 mm. brass, zinc, glass, porcelain.¹ Roiti (*Rend. Acc. Linc.*, 52, p. 153) has also given the following as equivalent thicknesses: tin foil, 0.336 mm.; brass, 2 mm.; aluminium, 6 mm.; while combinations such as 1.5 mm. aluminium and .084 tin are equivalent to 1 mm. brass, but this is not true for other thickness than these. From similar results, the co-efficient of absorption of aluminium for plates .6 mm. thick is found to be ² .83, and for plates of more than 1 mm. to be .90.

Chemical Constitution. The striking transradiability exhibited by many organic substances is due to the fact that they are almost entirely composed of various combinations of such elements as hydrogen, oxygen, carbon, and nitrogen, which have low atomic weights, and it is found that *all* substances which contain only these elements are very transradiable, apparently the one exception being the alkalis. The introduction into any such com-

¹ V. Chabaud, *C. R.*, 122, p. 237.

² Benoist, *C. R.*, p. 379.

pound of even small quantities of any member of the phosphorus sulphur or halogens groups largely increases the absorption, and this is of course true of most metallic compounds. All metallic salts are relatively opaque, and exhibit curious differences among themselves; thus hydrogen ammonium phosphate is four times as opaque as the corresponding arsenate. It is also for this reason that even the partial calcification of bone is found to largely increase its nonradiability, which allows radiographs to be taken showing the distribution of bones in the body. But inasmuch as these differences only occur for certain classes of rays, they should not be made too much of. With the halogens in combination it is found that their absorptive power is in the same order as their atomic weights, for two bromine atoms are more nonradiable than six chlorine, and it depends upon the number of atoms present. The fluorides seem to be more absorbent than they should be in accordance with their position in the series.

A comparison between the atomic weights of substances and their relative radiabilities

brings out some curious facts, which were first indicated by Dewar,¹ while Barrett² had shown that the radiability in some cases increased much more rapidly than the atomic or molecular weights; the salts of ammonium NH_4 being very transradiable in comparison with those of lithium (7), and these in comparison with those of sodium (23), and potassium (39).

Hyndman and Cribb (B.A., Liverpool, 1896), first pointed out that the relation was really of a periodic nature, as shown in Fig. 13, and that the maxima and minima positions were occupied by the same elements as in a similar curve where the heats of combustion are plotted against the atomic weights. The radiabilities of gases are found to be sensibly in the same order as the conductivities,³ and as this does not depend upon the molecular weight, it would seem that in this case there is no marked connection. For great lengths of gas the absorption follows the usual law $I' = Ie^{-a\lambda}$,

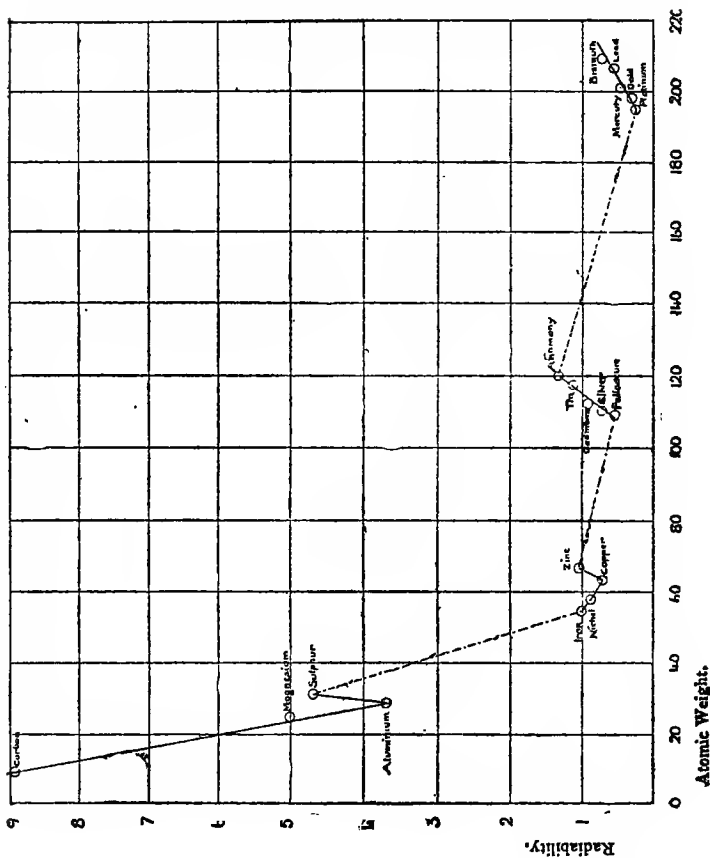
¹ *Proc. R. S.*, Feb., 1896.

² *Proc. R. S., Dublin*, May, 1896.

³ Rutherford, *Phil. Mag.*, 41, p. 241.

where α is the co-efficient of absorption and λ

Fig. 13.—Relation between Atomic Weight and Radiability.



is the length of the gas. For air α was found to be .001 while the conductivity may be put as 1,

then with chlorine, $\alpha = .0095$; conductivity = 18. Selective absorption has been found to exist for many substances, and is especially large in the case of eosin and fuchsine, while it is small for mica and paraffin, and negligible for glass; but it is obvious that all substances, which show different radiabilities to the X_1 , X_2 , and X_3 rays, must be selective in their absorption.

As compared with the transparency of objects to light, it is very striking that while in both cases every substance is at least slightly radiable if a sufficiently thin layer be experimented with, the actual number of what might be regarded as nonradiable substances to the X rays is very much smaller than in the case of light. Pupin¹ states that every substance on which the rays impinge at the same time emits them, which would seem to indicate that in many cases, if not in all, the radiability is more apparent than real.

In some cases the nonradiability is caused, not by any natural incapacity of the substances under examination to transmit the rays, but

¹ New York Academy of Science, April 6th; see also Röntgen, *Jour. de Phys.*, 5, p. 189.

simply because the latter are taken up in producing some change in the condition of the absorbent, either of a chemical or a physical nature. Thus it would naturally be expected that substances which fluoresce would be non-radiable to the active rays in the order of the brightness of their fluorescence, as the larger the proportion of the rays that undergo degradation the smaller the proportion that would be free to emerge unchanged. Non-radiability due to chemical causes is seen in the case of photographic emulsions, and the phenomenon in this instance is more easily investigated inasmuch as it is difficult to stop at once the fluorescence of a fluorescing body. The action of the X rays on a sensitive film must perforce come to an end as soon as the maximum amount of reduction (depending of course ultimately on the number of molecules of the reducible compound present) has taken place. Then the rays, having no longer any chemical work to perform, are free to pass through the film unless any physical cause prevents them, the previously nonradiable film thus becoming permeable.

Some experiments of Hyndman and Cribb's (*loc. cit.*) show this in a most striking manner. Two packets, each containing twenty-four sheets of bromide paper, were made up. In one packet the twenty-three top sheets were thoroughly exposed to light, the remaining sheet and the whole twenty-four of the other packet being left in their originally sensitive condition. A silver disk was placed on the top of each pile, which, after being wrapped in light proof paper, were exposed side by side at an equal distance and for the same time to the rays from a focus tube.

On developing the sheets the shadow of the disk, in the form of a white circular patch, appeared on the bottom sheet of each package, but was only just visible in the case of that from beneath the *unexposed* sheets, and the sheets all showed the image with a gradually increasing contrast as the top was approached.

In the packet of exposed papers of course all the top twenty-three sheets turned black at once on development. The *bottom* sheet, however, showed the white shadow of the disk with all the vigour and contrast exhibited by

the *top* sheet of the other packet, although the rays had had to pass through twenty-three sheets of paper the same in every respect, except that of short exposure to light, as the twenty-three sheets of the other pile. Hence passage through twenty-three sheets of sensitive paper previously exposed to light produced no appreciable diminution in the photographic activity of the rays, while the interposition of the same number of *unexposed* sheets was sufficient to almost entirely rob them of their power.

A similar phenomenon was also observed when exposed and unexposed bromide or gelatino-chloride papers were held in front of the fluorescent screen or exposed over sensitive plates. Whether the image was latent or developed, the exposed papers were relatively highly nonradiable, while a similar number of unexposed sheets cast an intense shadow. Other papers, such as platinum, ferroprussiate and carbon (bichromatised gelatine) did not show any such effect.

Time. From *a priori* considerations one would naturally expect that some

difference in radiability would be shown for short and for long exposures, even if (see p. 232) there was no obvious change produced in the medium. Dwelshauers-Dery has observed that the radiability of most substances increases with prolonged exposure, of alum and silica (agate) first increased and then decreased, while that of obsidian continually decreased.

Edison has mentioned that with fluorite the fluorescence only penetrates $\frac{1}{18}$ " in a second.

§ 5. Fluorescent Effects.

The occurrence of such changes in the case of the X rays constitutes an important argument in favour of their being vibrations of a nature resembling those to which their absorption gives rise.

Röntgen, in his first paper (*loc. cit.*), mentions the fluorescence of barium platino-cyanide, calcium sulphide, uranium glass, etc. Others have investigated many substances, and it seems possible that all bodies may be capable of lumi-

¹ *Bull. de l'Akad. Roy. de Belgique.* No. 6.

nescing, under suitable conditions, when acted on by the rays, which compares curiously with the marked increase in phosphorescence observed by Dewar at low temperatures (p. 94). Had the rays been of a more stable character, and not possessed this liability to change, it is possible that they would have yet remained undiscovered.

The nature of the substance has a marked effect on the amount and colour of the radiations emitted, for these seem to differ considerably. The following are substances which give a marked fluorescence, those giving the best results being put first in each group :—

Platino-cyanides of : Lithium-rubidium, potassium, barium.

Tungstates of : Calcium (scheelite).

Sulphides of : Calcium, barium, zinc.

Fluorides of : Ammonium-uranium, calcium (fluor spar).

Solid solutions : Copper tungstate in calcium tungstate.

Uranium salts : the nitrate and the glass.

Lead minerals : Cerrusite.

Halides : Rubidium (Rb I), rock salt.

The first point to be considered is the fluorescence of the tube, or rather of the glass of

which it is made. The phenomenon probably resembles those obtained by Crookes with the rare earths, rather than those which will be mentioned ; for even if the X rays are produced inside the tube and not on the tube wall, their passage through this must considerably modify their nature on account of the absorption of the glass. The connection between the luminescence of the glass and the production of the rays will be found discussed on page 211, and it seems that the nature of the glass, as shown by the colour of the fluorescence, has some influence, the best glass being that which gives a yellowish green colour. For further details about the phosphorescence of substances in the tube, the chapter on the cathode rays should be consulted.

The nature of the substance affects both the nature and the intensity of the radiations emitted, while its physical condition seems to only affect the latter ; the former will be considered when the other points have been discussed.

Some of the substances which do and which do not fluoresce have been mentioned above ;

among these the failure of the silver halides, with or without gelatine, is to be noted. The author did not get any fluorescence with the films and papers he tried, including platinum, carbon, and ferro-prussiate papers.

The action of the rays on a photographic plate was attributed, by the earlier observers, to the fluorescence of the sensitive film, but the author's experiments appear to show that this cannot be the case. Considerable advantage has been gained, however, by putting fluorescent substances into the emulsion, though it tends to make the texture of the negative coarse.

As mentioned above, the intensity of fluorescence is largely affected by physical conditions. It is found that all the substances which give the best results are crystalline, and the perfection of the crystals has a considerable influence; so that if a finely grained screen is wanted, it is usually preferable to obtain small crystals rather than to powder large ones. It has been observed that the platino-cyanides, in particular, work best when they are moist.

Great purity is sometimes by no means an advantage, and in several cases it has been

shown that a small quantity of some other substance is distinctly beneficial; thus solid solutions of copper or manganese tungstate in calcium tungstate give much better results than either of these salts separately. Native calcium tungstate or sheelite was reported by Edison¹ to be considerably more efficient than any platinocyanide, and later, Giazzi (*Nature*, April, 1896) described an improved method for obtaining the salt in the right condition artificially, though most European workers still use the platino-cyanides.

The question as to whether the photographic action is primary or is due to the fluorescence of the film or of the backing is by no means settled, for cases have been mentioned which seem to prove both hypotheses. Against the primary action the observation of C. Maurain,² that Daguerreotype plates show no effect, is somewhat pertinent.

Fluorescent screens enable the eye to see the shadows of objects which are opaque to the rays, by converting the invisible radiations that

¹ Telegram to Lord Kelvin, *Nature*, 1896.

² *L'Eclair Electric*, 7, p. 549.

fall on the unshaded parts, into light. These latter then appear bright and the shaded parts dark, giving the same appearance to the eye as would be obtained by throwing a shadow of the opaque parts alone on to a piece of ground glass illuminated by light.

It is thus owing to the different relative radiabilities of substances to the X rays and to light that the shadows can be seen of objects invisible to the eye by reason of their being covered up by other media. This is very different to being able to see through opaque objects, with which it has been confused ; a feat probably impossible on account of the structure of the eye, as the retina seems not to fluoresce with the rays as it does with light. Röntgen used the screen for the above purpose, and Salvioni was one of the first to enclose it so as to shut off extraneous light by a cardboard tube, a device which he christened a cryptoscope. Such a device has been largely used in surgical diagnosis, its principal disadvantage being a want of definition, due partly to construction and partly to the want of a better source of the X rays.

Much has already been done in both these directions, and no doubt screens in the future will largely supersede the photographic plate on account of their simplicity, when they can be made to give an amount of detail approaching that obtainable by the cumulative action on the plate.

Fluorescent screens may also be used very advantageously in conjunction with the photographic plate or film. They have been used by some experimenters in front¹ of, and by others behind,² the film.

The results of different workers resemble each other so much that it is unnecessary to give a separate account of each, and only the points of difference will therefore be mentioned.

The two methods mentioned above differ somewhat in principle. In the first, with an efficient screen, the action on the photographic plate is largely due to the light and other radiations emitted by the screen, while probably

¹ Blackrode, *Nature*, April 16, p. 557; Pupin, *Trans. Acad.*, New York, March, 1896, and April, 1896.

² Heurck, *Annales (Belges) de Pharmacie*, March 1896; Swinton, *Nature*, April 16, p. 557, 1896.

very little is to be attributed to the direct action of the rays. In the second, however, the X rays act first on the sensitive film, and the residual energy, after traversing the support, is sent back by the screen as light. To derive much benefit in this method the support must not absorb the radiations, so that it should be made of celluloid or some similar material, and not of glass, which is particularly objectionable in this respect (p. 223).

It might be advantageous to employ screens both before and behind the film. This does not seem to have been yet tried beyond the employment of the usual photographic plate in the first method, the glass basis of which frequently fluoresces brightly, sometimes as well as a prepared screen. The fluorescent effects of the X rays appear to be very analogous to those produced in the same substance by light, and in most cases the duration of the luminosity is practically coterminous with that of the rays, though some substances exhibit distinct phosphorescence.¹

The nature of the radiations emitted by

¹ Henry, *C. R.*, 123, p. 400.

fluorescent substances under the action of the Röntgen rays is very varied, and it is probable that, besides those visible as light, there are others which will be found to partake more of the nature of the radiations discovered by Le Bon (p. 282) and Becquerel (p. 275), since it has been shown that a large proportion can pass through black paper, but little through glass.

Henry (*C. R.*, 122, p. 312) mentions a curious experiment. A coin was covered on one side with phosphorescent zinc sulphide, and was placed over an iron wire lying on a sensitive plate, and the whole exposed to the X rays. The result showed the shadow of the wire behind where the coin had been, whichever side of this was next to the plate (cf. p. 275).

The spectra of the radiations emitted by fluorescent salts only show the characteristic lines of the metal, the spectra of different salts of the same metal being identical, the acid radical apparently only affecting the intensity.

Barium platino-cyanide is mentioned as having emitted, under the action of the X rays, a light of such a colour that the wave length for maximum brilliancy was about $\cdot 5 \mu$, while, with

light under the same conditions, the wave length was about 0.460μ .

Also it was found¹ that fluor-spar emits radiations having an index of refraction 1.48, through a prism of fluor-spar which corresponds to a wave length of 219μ . Several workers have proposed that fluorescence should be utilised for radiometry on the principle of a half-shadow photometer,² the two halves of the disk being respectively illuminated by the radiations to be measured, and by a standard source of light, which is brought to the corresponding colour by the use of tinted glasses.

§ 6. Interference and Diffraction.

The demonstration of these phenomena is difficult with any other electro-magnetic radiations than the visual ones, so that, in view of the peculiar properties of the Röntgen rays, it is not to be wondered at that up to the present no satisfactory demonstration of the existence or non-existence of these phenomena

¹ Winkelmann and Straubel, *Jen. Zeit. f. Nat.*, 30, 1896.

² *C. R.*, 123, p. 400.

has been given. Of the various methods of producing interference of light waves mentioned on p. 112, only one is available, viz., reflection at glancing incidence from plates placed at a small angle to one another.

The detection of interference could only be accomplished by photographic means, and it is here that probably one of the principal difficulties arises; for when we consider the wave length which has been assigned to the Röntgen rays, and compare this with the constitution of the usual photographic emulsions, in which the respective relationships of the aggregates of silver salt to the medium more resembles that of a pea to a quart of jelly than the desirable continuity. Even should this difficulty be surmounted, the heterogeneity of the rays, as at present produced (p. 211), would probably vitiate the results obtained, and it is probable that nothing can be satisfactorily done in this connection until a more homogeneous radiation is obtainable.

However, several observers have published results, stating that they have obtained both interference and diffraction bands, and in some

cases giving numerical data. Thus Fomm¹ has used a method in which interference bands are caused to move across the screen by altering the width of the slit, this gave $\lambda = 140 \times 10^{-10}$ m. Sagnac,² by the use of a wire grating, has arrived at the value 400×10^{-10} m., and Calmette and Lhuiller³ at 160×10^{-10} m., which is the same value as Precht⁴ found by a diffraction method.

§ 7. Polarization.

The possibility of polarizing the X rays would, if proved, be of the very highest importance in determining their nature; for it was shown for light that the radiant matter theory could not be reconciled with this phenomenon, and no polarization of a longitudinal variation of energy can be conceived. Of the three possible methods of polarizing of a ray, that by absorption is the only one available, and, as pointed out by J. J. Thomson, the number of substances that are likely to do this must be very limited.

¹ *Wied. Ann.*, 59, p. 350.

² *C. R.*, 122, No. 13.

³ *C. R.*, 122, No. 16.

⁴ *Wied. Ann.*, p. 330, 1897.

Röntgen (*loc. cit.* 1895) tried the experiment with tourmaline plates, and was followed by others using various substances, including this and calc spar, but for some time without any positive results; however, Galitzine and Karnojitzky¹ report that they have obtained evidence of polarization with thin green-brown tourmaline, .52 mm. thick, the results being multiplied by superposition of the images. These experiments require confirmation, as so many previous operators failed to obtain the same result.

One of the principal difficulties in the use of tourmaline, or calcite, is their comparative nonradiability, for which reason herapathite² (iodo-sulphate of quinine), among other substances that were tried, seemed very likely to be satisfactory on account of its radiability and high density; but only negative results were obtained.

The usual method adopted is that of exposing a photographic plate below two sets of crystal

¹ *Mem. Acad. Sci., St. Petersburg*, 3, No. 6, p. 1, 1896.

² Mayer, *Nature*, p. 522, April, 1896.

sections at the same time, each set being composed of two plates, each of which is cut parallel to the optic axis of the crystal. The optic axes are parallel in one case and at right angles in the other, so that if the plates had any polarizing effect the image would be lighter under the crossed than under the uncrossed plates.

To account for this difficulty in obtaining any polarization it has been suggested that the X rays are polarized already.

If they were plane polarized, the same and no more difficulty would be experienced in finding some medium to analyse them than if they were unpolarized. If circularly polarized, however, they would have to pass through a thickness of some substance, not differing very much from a quarter wave plate, which had the power of converting them to a plane-polarized radiation, before they could be tested with an analyser, and hence the difficulties would be enormously increased.

§ 8. Influence on Distribution of Electricity.

The subjects to be considered under this heading are :—

1. The changes in the distribution of electricity caused by the action of the rays.
2. The behaviour of the rays when in an electrical or magnetic field.

Among the properties connected with the distribution of electrical charges, one of the earliest observed was concerned with the effect produced when the rays are allowed to fall upon a charged body, such as an electroscope, Benoist and Hurmuzescu¹ first announcing that a charged and insulated body lost its charge when subjected to the action of the rays, and that a negative charge leaked away more rapidly than positive. Bourgmann and Gerchun² find that a positive charge becomes converted into a negative, and that a negative falls to a certain constant value; but Righi,³ Henri,⁴ and J. J. Thomson⁵ maintain that the

¹ *C. R.*, 122, p. 235.

² *C. R.*, 122, p. 376.

³ *C. R.*, 122, p. 376; confirmed by Lussana and Cinelli, *N. Cim.*, 4, 3, p. 364.

⁴ *C. R.*, 122, p. 378.

⁵ *Nature*, Feb. 1896, p. 292.

rate of leak is the same for both positive and negative charges, though the former considers that there is a positive residual charge. Reid¹ makes also the curious statement, which does not seem to have been further worked out, that tubes containing oxygen and hydrogen emit rays which *increase* the deflection of a negatively charged electroscope.

The dissipation of the charge is accompanied by the production of an opposite charge² on the walls of the room or the enclosure, and, apparently, the discharging action of the rays is at right angles³ to their direction.

The principal factors which determine the rate of leakage in any particular instance are three in number.

The Nature of the Substance.	This factor has a very marked effect on the rate of fall of potential, and it is found that the order of activity of various conductors is that of decreasing density and nonradiability, ⁴ and is approximately that
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¹ *Nature*, March 19, p. 461.

² J. Perrin, *L'Eclair El.*, 7, p. 545.

³ Villai, *Rend. Acc. Linc.*, 5, 1, p. 445.

⁴ Benoist and Hurmuzescu, *J. de Phys.*, 5, p. 358.

of decreasing atomic weights in the case of the elements; the rate of leakage from platinum being about twice as fast as from aluminium. Benoist and Hurmuzescu¹ consider that the order for the X rays is platinum, mercury, silver, zinc, aluminium, and for ultra-violet light (p. 137), silver, platinum, mercury, zinc; but Righi² considers that the order should be the same for these and should agree with that for the E.M.F. of simple contact.

Further investigation³ on the same subject seems to show that each substance has a potential of a particular magnitude and sign, which it tends to acquire when subjected to the rays whatever the magnitude or sign of its original charge may be. This may account for some of the apparently contradictory results obtained by the earlier observers. It is worthy of notice that a plate which was coated with paraffin wax on the side which was turned towards the tube, discharged⁴ from the other

¹ *C. R.*, 122, p. 779.

² *C. R.*, 122, p. 878.

³ Minchin, *Nature*, p. 524, 1896.

⁴ E. Villari, *Rend. Acc. Linc.* 5, 2, p. 35.

side, and that when both were covered there was no discharge.

The Surrounding Dielectric.

The nature of the dielectric principally influences the *rate* of leakage of the charge, and certain substances, such as paraffin, gum, and ebonite, cease to allow a discharge to pass when they become in electrical equilibrium with the charged body.¹ Ether and turpentine also give a rapid discharge at first, which slowly ceases. In gases the factors investigated are atomic weight (density) and pressure. Of these the first has a very marked effect, for it has been shown² that, *cæteris paribus*, the leakage is about twice as fast in air as in hydrogen, and increasingly fast in carbon dioxide, the halogens in the order of their atomic weights, and in mercury vapour. It appears to vary approximately as the square root³ of the density. When the leakage takes place between metallic plates in the air, these exhibit marked polari-

¹ Villari, *Rend. Acc. Sci.*, Naples, 2, 6, 7, p. 214, 1896.

² J. J. Thomson and McClelland, *Nature*, p. 568, 1896.

³ Benoist and Hurmuzescu, *C. R.*, p. 122, p. 926.

zation. The rate of leakage was found to vary as the square root of the pressure,¹ and a higher² pressure is required to get the same rate than with ultra-violet light.

It is curious that the ratio of the conductivity of various substances much resembles that of the dielectric coefficients for the same substances, the rules by which the values can be roughly calculated being the same in the two cases.

When the gas which has been subjected to the X rays is blown against a positively electrified wire, it is found to have lost the power of discharging positive electricity (Villari, *C. R.*, July 3, 1897), but to be still able to discharge negative, the converse being true for a negative wire.

The leakage of electricity from a substance under the influence of the rays thus appears to depend on both the substance and the dielectric. The relation was shown to be an additive one by Perrin (*Ann. Chem. et Phys.*, 11, 496), who distinguishes the metal effect and the gas effect.

¹ J. J. Thomson, *Nature*, Feb., 1896. ² Righi, *loc. cit.*

The Nature
of the Charge.

Thomson and McClelland (*Nature*, Feb., 1896) have shown that the rate of leakage is proportional to the difference of potentials when this does not exceed three volts. As this is increased the leakage also increases, but more rapidly, until at a certain value the rate becomes practically independent of the potential difference. The conformance with Ohm's law¹ is also found to be good up to a potential difference of 278 volts.

These phenomena seem to show that the rays have the power of being conductors of electricity, or of causing all substances to be so which they traverse, even when normally perfect insulators. Thus paraffin, wax, sulphur, ebonite, mica, and all gases become conductors. Benoist,² however, considers that the leakage is due to a process of convection in the dielectric. This view receives some support from certain experiments of Villari,³ in which he finds that a current of air in the direction of, or contrary to, the rays can hasten or almost

¹ J. J. Thomson, *Nature*, Feb., 1896.

² *C.R.*, 122.

³ *Rend. Acc. Linc.*, 52, p. 35.

prevent discharge. That the rays do not themselves act as conductors seems proved, for they can pass between bodies of very different potentials¹ if these are not already connected by lines of force.

To account for the conduction, J. J. Thomson² proposes the view that there is a process somewhat analogous to electrolysis, there being a partial dissociation into atoms, and E. Murray's³ experiments seem to confirm this, for he found that the air between the two metallic plates of an air condenser behaved as a drop of acidulated water, discharging or perhaps slightly reversing the polarity of the plates, the rays in some way or other being supposed to play the part of the solvent.

Frankland⁴ disagrees with this theory, since he failed to find any change in the rotatory power of ethyl benzoyl glycerate and methyl acetyl glycerate, under the action of the rays. This indicated that there was no ionization, though these substances have been shown to

¹ J. Perrin, *L'Eclair El.*, 7, p. 545.

² *Nature*, 1896, p. 372. ³ *Proc. R.S.*, March 19, 1896.

⁴ *Nature*, 1896, p. 556.

dissociate in solution. The negative results obtained were considered quite definite.

Experiments on the influence of the Röntgen rays on the formation of clouds¹ caused by the sudden expansion of air, have shown that the cloud is considerably denser during or after the passage of the rays than if these are absent. This is by no means conclusive, as the question of cloud formation is still under discussion; but in conformance with the accepted view, this experiment would be in favour of the "solid particle" theory for the X rays. On the electrolysis theory the ions are supposed to act as nuclei.

Gases, such as air, coal gas and certain mixtures of vapours, which have been subjected to the action of the rays are found to possess the property of dissipating an electrical charge even after passing through ten meters of glass or lead tubing,² but lose this property rapidly, by contact with substances having a large surface, such as cotton wool or wire gauze.³

¹ C. J. R. Wilson, *Proc. R.S.*, March, 1896.

² E. Villari, *Rend. Acc. Linc.*, 5, 2, p. 93.

³ W. Röntgen, *Journ. de Phys.*, 5, p. 189.

Theories of convection or electrolysis are easily applied to gases, but the question becomes much more complicated when applied to solids ; for although the researches of Roberts-Austen, (*Nature*, May 21, p. 55), on the diffusion of metals in metals indicate that considerable molecular migration is possible, yet the process is one of some duration, while the leakage of an electric charge through a material such as ebonite, when exposed to the rays, is comparatively rapid.

Röntgen has shown that a radiable magnetic shell is capable of preventing the rays from causing an enclosed body to lose its charge, which seems to show that the phenomenon may be dependent on other factors than those discussed above.

The difficulty of explaining the mode of conduction in this particular case is all the greater in the face of the real want of knowledge with regard to the mode of any conduction whether of electricity or heat. No one has suggested a satisfactory reason for the bad conductivity of some metals in comparison with others, and it seems quite as reasonable

to suppose that silver conducts electrolytically under normal conditions as to suppose that glass can do so under the action of the rays. The experiments of Sella and Majorana¹ show that substances do not always become conductors, for they found that when the terminals of a spark gap are more than 30 mm. apart, the spark can be prevented from passing by causing the rays to fall on to the gap, or better upon the positive pole; and that ultra-violet light produced the same effect. However with spark gaps of less than 30 mm. the phenomenon was normal. Righi also states that nongaseous dielectrics do not become conductors.

The rate of leakage seems to be largely dependent upon the magnitude of the current employed to traverse the gas, and perhaps also to depend somewhat upon surface effects, for, as stated above, Thomson and McClelland found that the conductivity varied as the square root of the pressure with the currents they employed, which were small; with large currents, on the other hand, the conductivity is found to

¹ *Nature*, May 21, p. 53. *Rend. Acc. Linc.*, 5, 1, pp. 323.

vary as the density, the result obtained by Hurmuzescu. The explanation is to be sought in the relation between the conductivity and the number of ions conveying the current. The expression contains a term αn^2 where n is the number of ions which recombine per second. With saturation currents n would be very small, and hence n^2 would be negligible though it is important with small currents where n is large.

More recently J. J. Thomson (*Phil. Mag.*, Oct. 1897), has measured the value of these saturation currents under different conditions, and also the time during which the conductivity of the gas which has been subjected to the rays (Röntgenised) sinks to half its value; from these measurements he is enabled to calculate the velocity of the charged ions and the charge carried by them.

Photo-Electric Cell. The action of the X rays on a selenium cell of the Shelford-Bidwell type¹ was investigated by Haga.² The cell, the resistance having been first measured in

¹ *Nature*, November 18, 1880. ² *Nature*, 1896, p. 109.

the dark, was covered by a thick sheet of zinc and exposed to the rays. Under these conditions the passage of the current through the tube produced no change. A thin double screen of aluminium was then substituted for the zinc sheet, the coil worked for one minute and the resistance measured; this took about another minute; twenty minutes after the resistance was again measured.

Resistance in Ohms	In the Dark.		In Diffuse Daylight.		After 1 min.		After 20 min.	
	}		}		}		}	
	31,600	...	15,300	...	26,400	...	29,500	

Threlfall and Pollock (*Phil. Mag.*, p. 453, 1896), however, consider that the effect is comparable with that produced by diffuse daylight. A reduction in E.M.F. is also observed when platinum foil coated with silver bromide is exposed to the rays.

The electro-chemical properties of the rays are not marked, but were investigated by Streenitz (*Phil. Mag.*, 41, p. 462).

The Röntgen rays were thought by two early observers¹ to affect a radiometer, but

¹ Gossart and Chevallier, *Compt. Rend.*, 122, p. 315.

further more complete experiments¹ have shown that the supposed mechanical action was really due to electrostatic causes; if these and thermal effects are excluded by a thin aluminium screen, the rays are found to have no action on either a radiometer or a thermopile.

Magnetic Field. The influence of a magnetic field was first investigated by Lafay.² His earlier experiments were made with rays which had passed through an electrified metallic plate, but subsequently with the direct rays, and in both cases he found a deflection. The "electrified" rays charged a Faraday cylinder with electricity of the same kind as that of the plate which they had traversed, and their deflection was reversed, if the sign of the electrification of the plate was changed.

Lodge (*Electrician*, June, 1896) has shown that in these deflection experiments no precautions were taken to avoid displacements of the apparatus due to magnetisation by the powerful

¹ Fontana and Umani, *Rend. Acc. Linc.*, 5, 1, p. 170; and T. C. Porter, *Nature*, June, 1896.

² *Compt. Rend.*, 122, pp. 713, 809, 837, 929.

fields employed ; to avoid this he investigated the case of a possible rotation, sending the rays along the axis of a powerful electro-magnet. In their path were placed three metallic wires, which were so arranged that they gave parallel images ; if there was any rotation one of the wires would cease to be parallel to the other two. The experiment was tried with air and with glass as dielectrics ; in the latter case a potential difference of 100,000 ohms was employed, but in neither case was there the slightest deviation.

§ 9. Physiological Effects.

The effects which have been observed can all be attributed to a nervous stimulus, which shows itself by disturbing either the heart or the vascular blood system. The action of the rays on the heart¹ or the eye occasions intense throbbing,² while on the skin it causes primarily intense dryness with subsequent loss of the cuticle, and after a long time, and in some cases, what are apparently true burns.³

¹ Seguy and Quenisset, *C. R.*, 124, p. 790.

² *Electrician*, 38, p. 291. ³ Lannelongue, *C. R.*, 124, 828.

The action is not felt at once, usually taking some days to reach a maximum, and it is largely influenced by the distance and source of the rays ; it is also noticed that a thin earth-connected aluminium plate¹ cuts off the action entirely. Different persons exhibit marked variations² in the ease with which they are affected, and it is curious that the effect on mummy skin should be to soften it.³

Much nonsense has been written about being able to see the rays, but there seems no doubt⁴ that some people can perceive when non-radiable objects are placed between their eyes and a source of X rays ; this seems to be especially true with people who have lost the crystalline lens,⁵ probably on account of its nonradiability.

It would be expected that some effect might be shown with lower forms of life, and it is found that with mice⁶ there is a powerful nervous stimulus but no increase in the CO_2

¹ Destot, *C.R.*, 124, p. 1114. ² Crookes, *C.R.*, 124 p., 855.

³ *Proc. R. Soc.*, 1896. ⁴ Röntgen, *Sitz. Berlin.*, 576, 97.

⁵ G. Brandes, *Sitz. Berlin.*, 24, 547.

⁶ S. Capranica, *Rend. Acc. Linc.*, 5, 1, p. 416.

evolved; experiments have also been tried on guinea-pigs.

Their action on bacteria does not seem general; for although tuberculosis bacilli¹ are said to have been destroyed, no effect could be found on typhus² cultivations in agar-agar.

§ 10. Chemical Effects.

The action of the X rays on such photo-sensitive substances as the silver halides is one of their best known properties; their influence on the radiability of photographic emulsions has been considered on p. 252, and another aspect on p. 232. The general evidence seems to point to the conclusion that the rays do primarily affect the silver and other salts,³ and it is hence remarkable that they have little activity in other reactions. Dixon showed (*Trans. Chem. Soc.*, 1896, p. 788) that they did not cause any combination between CO and O₂, while subsequently with Baker (*loc. cit.*, p. 1308) the investigation was extended to

¹ Lartel Genoud, *C. R.*, 122, p. 1511.

² Renzi, *B. M. J.*, Oct., 1896.

³ Sanderucci, *N. Cim.*, 4, 3, p. 353.

many photo-sensitive mixtures, some of which show decomposition as H_2O_2 , some combination as $\text{CO} + \text{Cl}_2$, H_2SO_4 Aq + O_2 , $\text{H}_2 + \text{O}_2$ with light; but in every case negative results were obtained. The influence of the Röntgen radiation appears to be very slight with such combinations as AgNO_3 in alcohol, HgCl_2 in ammonium oxalate solution, as shown by de Hemptinne (*Zeit. Phys. Chem.*, 1896, p. 493). Exposure to the rays produced no change in such reactions as the hydrolysis of ethyl acetate or on the conductivity of solutions of electrolytes, though they cause ionization in gases.

It is stated by Vandevyver (*J. de Phys.*, 1897, p. 23) that the action of the rays on a sensitive film varies inversely as the distance between them instead of inversely as the square of the distance.

§ 11. Theories.

The nature and origin of the Röntgen rays are by no means definitely settled, although the balance of opinion seems to be in favour of there being some form of transverse ethereal vibration. However, many other views have

should these properties be negative, for with a radiation strictly analogous to light, but of very short wave length, it is possible that the principal absorption band for all substances would correspond to a slightly longer wave length, in which case the dispersion would be abnormal and the index of refraction could easily be unity, (cf. p. 102).

Against the minuteness of the waves we have the fact that the Röntgen rays possess chemical and fluorescent effects so similar to the actinic rays that they are unlikely to differ much from them in size.

Sir G. Stokes' view (*Proc. Camb. Phil. Soc.*, 1896) removes this difficulty, for with the very short trains he supposes, we might well be dealing with waves of a frequency differing very little from the actinic rays and yet not possessing the properties of interference, polarization or refraction. The main difficulty is to grant the possibility of such waves at all. This view has been further extended by J. J. Thomson (*Phil. Mag.*, Feb., 1897), who gives the mathematical theory on the assumption that the X rays are the return

electromagnetic pulses caused by the stoppage of the highly electrified particles composing the cathode rays. The magnetic force due to a moving particle at a point distant r units from it $= \sin \theta \, we/r^2$, where θ is the angle between the path of the particle and the direction of the point from it. This pulse lasts for a time $(r-a)/v$ where v is the velocity of light and a is the radius of the particle. If this is suddenly stopped the return pulse is $= \sin \theta \, we/2 \, ar$, and hence is $r/2a$ times the direct and of a thickness equal to $2a$.

Jaumann assumes that the X rays are longitudinal waves with a transverse component thus continuing and expanding Röntgen's original view. The theory appears to agree with the few phenomena by which it has been partially tested, but it will require very definite proof before it is likely to be accepted. It has many points of resemblance to Jaumann's theory of light (p. 44). The theories included in No. 5 postulate phenomena closely allied to those with which we have some acquaintance, which the others do not.

The vortex theory is equally applicable to

the cathode rays; in fact, its author considers that these are identical with the Röntgen, the latter being, in his opinion, simply the cathode rays modified by the selective absorption of the tube-wall. The vortices are supposed to be generated in the cathode and to be forced out by the negative charge. To account for their non-appearance at higher pressures he supposes that the energy of the current is used up in giving charges to the molecules of the gas, but that as exhaustion proceeds more of the energy becomes available for the production of vortices. The vortex ring would behave with substances it encountered as a smoke ring does with wire gauze, and many of the observed properties would be quite compatible with this. Owing to the comparatively slow velocity of vortex rings, a determination of the rate of transmission of the X rays would probably decide the question.

The radiant matter theory is an old friend. It has been applied at one time or other to every known form of radiation, excepting radiant electrical energy, where it was never considered to be admissible (see p. 2).

It has been too readily assumed by some

writers that the cathode and the X rays are necessarily of the same nature. Even should the cathode rays prove to be streams of electrified particles (see p. 201), it seems quite reasonable and sufficient to suppose that the bombardment by these of some solid object, or even of the residual molecules of gas in the vacuum tube, may give rise, by the molecular vibrations induced, not only to oscillations of the ether, which affect our senses as fluorescent light emanating from the wall of the tube, but also to other oscillations of a different nature.

The origin of the rays has been the subject of much investigation, and in view of the few cases in which they have undoubtedly originated from other sources than a vacuum tube, p. 206, the subject is still in a chaotic state. Where vacuum tubes are used much seems to depend on their construction, but as yet no general law has been found between this and the origin of the rays.

A reference to the section on production will show that the most general form of tube has a plate of metal, often concave, at the end of the cathode, and in the centre of curvature of

or opposite to this at the other end of the tube another metal plate, which is either at the end of the anode, or is insulated, and is then known as the anticathode, the anode in this case being in such a position that it is not struck by the cathode rays. This plate is frequently turned so as to be at an angle of 45° to the plane of the cathode. In a tube of this construction it is clear that for external experiments practically the same results would be obtained if the X rays originated :

1. At the cathode, were focussed on to the anode or anticathode, and hence spread in straight lines through the glass.

2. At the anode by impact of cathode rays on this.

3. At the glass where the diverging cathode rays strike.

Besides these possibilities, the rays may have originated in the gas, and may or may not be necessarily connected with the cathode rays.

The following are the principal methods published for finding the position of the origin of the rays in the tube.

J. J. Thomson used the rays coming through

a small hole in a thick metal plate, and estimated their intensity at different distances by the rate of leakage of an electrical charge across an air space. The rate varied inversely as the square of the distance from a point, the position of which varied for each tube.

Since the rays are always divergent, the distances have been measured between the images produced, by allowing two rays coming through small holes in a metal plate to fall upon a plate or screen when at different known distances from the tube; thus arriving at the position of the apex of the triangle, or point of emission of the rays. This was also found² by measuring the lengths and positions of the shadows cast by nails driven into wood or cork, by the aid of a photographic plate or fluorescent screen.³ The balance of opinion puts the origin at the point where the cathode rays first strike some solid object,⁴ though Michelson supposes that his vortices are formed at the cathode (see p. 269).

¹ J. J. Thomson.

² Galitzine and Karnojitsky.

³ Burget, *C. R.*, 122, p. 608.

⁴ Battelli, *N. Cim.*, 4. 3, 128, 1896.

The nature of this seems to be immaterial; for although glass, aluminium, mica, platinum, porcelain were tried, no practical difference could be distinguished.

S. P. Thompson agrees with this view for tubes with an opposing metallic plate; and for those without, he thinks that the X rays may originate on the tube-wall, or in the gas, owing to the intense electrical field employed, and he suggests the use of other gases than air in the tube. An experiment in this direction, mentioned on page 250, apparently indicates a difference in the radiation produced when oxygen or hydrogen are used.

The position of the origin in the tube can be altered by several means, such as a magnet or a metallic point (see production), and in all probability the rays which are thus concentrated or deflected are cathode and *not* X rays; at any rate they differ very markedly from the X rays as known outside the tube, for Lodge has shown that these are *not* affected by a magnet. Although this fact would seem to invalidate all theories except the one which puts the origin at the tube-wall, yet so many

opinions have been published, ascribing almost as many positions, that it is necessary to give some account of them.

By some both the cathode and the anode are supposed to give rise to centres of emission, which may be a few mm. behind the glass or may coincide with them. Rowland and others, using a highly exhausted tube with electrodes only 1 mm. apart, found that the rays issued from the anode, and in another from two points between the anode and cathode, while in no case did the X rays seem to have any connection with the cathode rays.

A. Batti¹ observes that the bombarded surface continues to give off X rays after the current has been stopped, and that there is no essential difference² between the rays outside and the rays inside the tube which are not deflected by a magnet. He hence considers that there are two kinds inside the tube, and because there is an action on a sensitive plate inside the tube he assumes that the cause of this must be X rays, although the cathode rays have a similar effect (cf. p. 200).

¹ *N. Cim.*, 4. 3, p. 129.

² *Loc. cit.*, p. 289.

CHAPTER IV.

THE BECQUEREL RAYS.

SUBSEQUENTLY to Becquerel's discovery of an invisible radiation which was emitted by uranium salts, it has been found that other substances emit radiations which possess somewhat similar properties, and although they have not been shown to be identical with the Becquerel rays, they may be considered with them in the absence of any direct evidence to the contrary.

The first recorded observation of rays of this type was made by Henry (*C. R.*, 122, p. 662), who noticed that zinc sulphide emitted rays which were able to penetrate opaque substances, and that the effect increased with the temperature (cf. p. 243). Becquerel (*C. R.*, 122, p. 689) then observed that calcium sulphide emitted an intense radiation, and the same was noticed by

Troost (*C.R.*, 122, p. 564), and by him attributed to the existence of X rays. The true explanation of these phenomena was not obvious until Becquerel (*C.R.*, 1896, p. 581) published an account of investigations on the radiation emitted by the double uranium and potassium sulphate, in which their true nature was to some extent deduced. Subsequently it was found that uranium carbide and metallic uranium gave a more intense radiation (*C.R.*, 122, p. 1086).

It has been observed by both d'Arsonval (*C.R.*, 122, p. 456) and Niewenglowski (*C.R.*, 122, p. 385), that glass which had been impregnated with calcium sulphide emitted these radiations, but not to any extent until after it had been exposed to sun or electric light, and Troost (*loc. cit.*) found that artificial hexagonal blend emitted rays which resembled those from a Crookes tube.

It will be observed that many of the substances mentioned are fluorescent with light or become so under the influence of the X rays, and calcium sulphide is the only one which is appreciably phosphorescent. The uranium salts only emit visible radiations for

about $\frac{1}{100}$ of a second after the light is removed, while the Becquerel rays are emitted continuously and with apparently undiminished intensity for more than a year (*C. R.*, 124, p. 800), and uranium salts *produced* in complete darkness seem to emit nearly as energetic a radiation as those which have been exposed. An exciting agent does, however, increase the intensity of the radiation, the light from an electric arc or spark being more efficient than that from burning magnesium, or the sunlight (*C. R.*, 122, p. 689), showing that it is the *actinic* rays which produce the effect.

The radiations from any source are not homogeneous, as shown by Becquerel (*C. R.*, 122, p. 762) and Sagnac (*J. de Phys.*, 5, p. 193), and probably consist of a continuous series, like that exhibited by fluorescent substances.

Russel has found (*Proc. R. S.*, lxi., p. 424) that uranium is not the only metal that will give out rays of this type, but that a large number of others do so, though to a more limited extent, the following being the order of their activity :—

U, Hg, Mg, Cd, Zn, Ni, Al, Pb, Bi, Sn, Co, Sb.

This activity increases with the temperature, but is unaffected by the dryness and nature of the surrounding gas. Not only do metals emit these rays, but many other substances, such as copal varnish, which is more active when unfused; also wood and apparently all cellulose materials, such as strawboard, etc., which are more active when charred.

Radiability. The principal features in the penetrative powers of these radiations is, that the heavier metals are comparatively more transradiable for these than for the X rays, as also is quartz (Sagnac). A qualitative classification of some substances is given by Becquerel (*C. R.*, 122, p. 762) of which the following is a portion.

Very radiable. Paraffin, modelling wax (2 mm.), aluminium (10 mm.), copper (.08 mm.), platinum, and solutions of gold, copper, and uranium.

Less radiable. Uranium glass, silver, tin, cobalt glass; natural sulphur is more radiable than calcspar, which is more so than quartz.

Nonradiable. Zinc and lead, .36 mm. thick. A second layer of certain substances has a

different absorption to the first, and hence they exhibit a certain amount of selective absorption on the heterogeneous beam.

Electric Phenomena. Like the X rays and ultra-violet light, these rays have the power of causing any fluid substance which they traverse to become a conductor, and thus, when they fall upon charged substances, the charge becomes dissipated. This action can take place through 2 mm. of aluminium, and will dissipate positive and negative charges with equal facility, while the magnitude of the charge appears to be unimportant, between the limits of one and three hundred volts. Bodies which emit these radiations will then lose their charge gradually, with a rapidity which depends upon the power which the substance has of emitting the rays (see p. 277), and according to Becquerel (*C. R.*, 124, p. 438), also inversely as the square root of the density of the gas, the leakage at low pressures following the exponential law. The rate of loss of charge is also hastened when the surface is rough and when the gas is set in motion; all which data accord with the theory that the conductivity is

due to the ionization of the gas under the influence of the rays in a manner which is closely analogous to the similar phenomena observed with the actinic (p. 135) and the X rays (p. 250), a conclusion which derives some support from Wilson's observation, that they will produce nuclei for cloud formation in a dust-free gas (cf. p. 147).

Surface Phenomena. Unlike the X rays, which these radiations otherwise closely resemble, they are more influenced by a passage between media of very different densities, and show quite regular reflections, which may become total (Sagnac, *J. de Phys.*, 5, p. 193). Refraction was produced by the use of a crown glass prism by Becquerel (*C. R.*, 122, p. 689), and was found to take place in the same manner as light, the refractive index being also of the same order.

The possibility of polarizing the rays was also proved by both Sagnac (*loc. cit.*) and Becquerel (*C. R.*, 122, p. 762), who employed superimposed tourmaline plates, with their axes parallel and at right angles (cf. p. 248).

The investigation of these rays would have

had to depend entirely upon their power of dissipating an electric charge, had not they been able to affect rapidly and satisfactorily the photographic plates in common use, and it is by this means that the investigations on the penetrative power, the reflection, polarization, etc., of the rays have been performed.

Nature. It is, perhaps, rather a short time since their discovery to do more than bring forward the prevailing impression among physicists, which is that they are in reality ultra-violet radiations with a frequency of, perhaps, three or four times that of violet light.

CHAPTER V

LE BON'S RAYS.

UNDER the somewhat infelicitous title of "La Lumière Noir" Gustave Le Bon has described a number of phenomena, which seem to render probable the existence of radiations somewhat resembling those of Röntgen and Becquerel, in most sources of light.

It is stated (*C. R.*, 122, p. 188) that the light of the sun, or, with a corresponding duration of a petroleum lamp, if allowed to fall upon a sheet of iron covering a negative and a sensitive plate, so affects the latter, that it gives a normal though weak positive on development. Backing the plates with a sheet of lead, which could be brought into contact with the iron, is said to increase the effect. In another experiment the substance emitting rays was a frog, from which the viscous secretion had been removed

by alcohol. This was kept in complete darkness on a sensitive plate for two hours, with the result that the plate was affected; but the interposition of a glass plate prevented an action taking place.

These radiations appear to pass with ease through aluminium and copper, less easily through iron, and hardly at all through zinc, tin and silver (*C. R.*, 122, p. 233); while black paper is sometimes stated to be very radiable, and at others to be nonradiable.

The results are attributed by Perrigot (*C. R.*, 124, p. 857) and by Becquerel (*C. R.*, 124, p. 984), to the transparency, on continued exposure, of the supposed opaque substances; but this, though possibly true for ebonite, which even when 5 mm. thick is not quite opaque, can hardly be thought to be true for an iron plate. Le Bon has also shown (*C. R.*, 124, p. 1148) that these effects will occur even when the red rays, to which ebonite is particularly transparent, are cut off by green glass.

The discoverer has also published (*C. R.*, 124, p. 892) investigations on the discharging action of the rays which emanate from one side of a

metal plate when the other is illuminated, but these results bear a suspicious resemblance to those which are more usually ascribed to the Becquerel rays. It appears that the radiations from the following substances dissipated an electric charge in the times given :—

Zinc freshly amalgamated in 1 second.

Zinc ordinary, freshly polished aluminium 5–10 seconds.

Sn, Hc, Eb, Fe, ground glass, ebonite, card, paraffin,
20–40 minutes.

Cn, Co, Hg, An, Pt, Ag, 50–76 minutes.

Some substances cause the more rapid dissipation of a negative charge, and others of both equally, but in all cases a fresh surface has more effect than a dull one.

The presence of a sheet of glass between the metal plate and the *light* reduced the effect to $\frac{1}{300}$, which seems to show that the radiation is not an intrinsic property of the metal, such as the Becquerel rays appear to be (p. 277), but that it depends largely on the exciting radiation.

Many explanations of these phenomena have been advanced, one or two of which have been considered, and it seems possible that in reality

these radiations have no separate existence, and that some of the phenomena ascribed to them should be considered as due to one known source, and some to another. Thus Niewenglowski (*C. R.*, 122, p. 232), has shown that the positive mentioned on page 282 can be formed without any other cause than the known phosphorescence of the negative film.

The various ways in which it is said a sensitive plate can be affected so as to form a latent image are :—

(1) Mechanical friction, pressure (R. Colson, *C. R.*, 122, p. 598).

(2) Chemical reaction.

(3) Electro-magnetic waves from intense infra-red including fluorescent and phosphorescent radiations.

(4) Becquerel rays.

(5) Röntgen rays.

(6) Cathode rays.

(7) By an electric current or discharge.

(8) By magnetic field (*Photography*, 1896, p. 536).

(9) Psychological means? (Dr. Baraduc).

It seems probable that each one of the cases considered above would fall under one of these heads ; however, their discharging action is a good argument against this view, for it does

not quite resemble that of any other radiation, hence the question is still undecided.

Discharge Rays.

M. W. Hoffmann (*Wied. Ann.*, p. 269, 1897) has published an account of what he considers to be a new kind of radiation. It is stated to be emitted by an electric spark along its whole course, but more particularly at the cathode, and yet it is not considered as an ultra-violet radiation. The intensity of the rays increases as the pressure is diminished, and they acquire more penetrative power, they are undeflected by a magnet, are absorbed by oxygen and carbon dioxide gas, and when produced in hydrogen can penetrate quartz and fluorite.

These rays show rectilinear propagation, obey the law of inverse squares, and are detected by their power of inducing thermoluminescence. In fact, they very closely resemble the ultractinic rays observed by Hertz (see p. 66).

Glow-worm Radiation.

The radiation from glow-worms, fireflies, and the so-called phosphorescent marine creatures,

has been supposed to be almost exclusively luminous, probably because of the absence of thermal effects; but it is now found to contain a proportion of other rays, which, from the observations recorded up to the present, seem to occupy a unique position. Muraska (*Wied. Ann.*, 1896, p. 773), employed a large number of the large Japanese glow-worms, and found that the radiation appeared to proceed from the whole of the body, and that normally it had the character of light. When filtered through *metal* plates, however, it appeared to possess other properties, and penetrated tourmaline, solid fluorescein, topaz, and felspar 3 mm. thick.

In all cases, to affect a photographic plate the metal had to be in contact with it, but the effect was considered not to be due to contact. The statements are, however, somewhat contradictory, so that it will be necessary to wait for further work before giving any decision,

PERIODICALS AND ABBREVIATIONS

Abhandlungen der Königlich- Preussischen Akademie der Wissenschaften zu Berlin	<i>Abhandl. d. Berlin Akad.</i>
Alpine Journal	
American Journal of Mathematics	<i>Amer. J. of Math.</i>
American Journal of Science . .	<i>Amer. J. of Science.</i>
Annalen der Chemie : Justus Liebig's	<i>Lieb.: Ann.</i>
Annalen der Physik und Chemie : Poggendorff	<i>Pogg.: Ann.</i>
Annalen der Physik und Chemie : Wiedemann	<i>Wied.: Ann.</i>
Annales de Chimie et de Physique	<i>Ann. Chim. et Phys.</i>
Annales (Belges) de Pharmacie	
Archives des Sciences Physiques et Naturelles de Genève	<i>Archiv. d. Genève.</i>
Astrophysical Journal . . .	<i>Astrophys. Journ.</i>
Atti dell' Accademia Medico-chi- rurgica di Perugia	<i>Att. d. Perugia.</i>
Atti della Reale Accademia dei Lincei. Rendiconti	<i>Rend. Acc. Linc.</i>
Atti della Reale Accademia delle Scienze fisiche e matematiche Napoli	<i>Att. Acc. Sci. Napoli.</i>

British Medical Journal . . .	<i>B. M. J.</i>
Bulletin de l'Académie Royale des Sciences, etc., de Belgique	<i>Bull. Akad. Belgique.</i>
Bulletin de la Société Française de Physique	<i>Bull. Soc. Franç. Phys.</i>
Chemical News	<i>Chem. News.</i>
Chemiker Zeitung	<i>Chem. Zeit.</i>
Comptes Rendus des Sciences de l'Académie des Sciences, Paris	<i>C. R.</i>
Dublin University Experimental Science Association	
Electrical Review	<i>Elec. Rev.</i>
Electrical World	<i>Elec. World.</i>
Electrician	<i>Elec.</i>
Jenaische Zeitschrift für Naturwissenschaft	<i>Jen. Zeit. f. Nat.</i>
Journal de la Société Physico-chimique Russe	<i>Journ. Soc. Physico-chim. Russe.</i>
Journal de Physique	<i>J. Phys.</i>
Journal für Gasbeleuchtung . . .	<i>J. f. Gasb.</i>
Journal of the Society of Dyers and Cleaners	
L'Éclair Electrique	<i>L'Éclair Elec.</i>
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